Learning Science Through Inquiry in Kindergarten

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ABSTRACT: This paper examines the nature of kindergarten students' science learning from an inquiry unit in which they investigated the life cycle of the monarch butterfly. The unit was implemented in a public school serving a socioeconomically, ethnically, and linguistically diverse student population. The paper provides descriptive data on children's science learning from their investigations. The descriptive data were collected during the implementation of the inquiry unit using an electronic portfolio system. A second set of data on science learning was collected using an objective, researcher-designed instrument called the Science Learning Assessment (SLA). These data were collected from children in the intervention who completed the inquiry unit and from a comparison group of kindergarten students that was similar in demographic characteristics but did not receive systematic science instruction. The comparison group provides baseline data about kindergarten students' science concepts in the absence of targeted science instruction. There were 100 participants (65 intervention and 35 comparison students). Results indicate that intervention students demonstrated a functional understanding of scientific inquiry processes and of important life science concepts during their investigations. Statistical analyses of SLA data indicate that the intervention group showed significantly better understanding of scientific inquiry processes than the comparison group. © 2008 Wiley Periodicals, Inc. *Sci Ed* **92:**868–908, 2008

INTRODUCTION

The purpose of this study was to examine kindergarten students' science learning from an inquiry unit on the life cycle of the monarch butterfly. The unit was developed and implemented as part of a larger, federally funded, research project, the Scientific Literacy Project (SLP) (Mantzicopoulos, Patrick, & Samarapungavan, 2005). Children's science learning was assessed using two measures: (a) a student portfolio rating system and (b) an objective,

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individually instrument called the Science Learning Assessment (SLA) that was developed for the project (Samarapungavan, Patrick, & Mantzicopoulos, 2006; Samarapungavan et al., 2007).

THEORETICAL FRAMEWORK

National policy documents including the National Science Education Standards (National Research Council, 1996) and the Benchmarks for Scientific Literacy (American Association for the Advancement of Science, 1993) emphasize the importance of inquiry-based experiences to foster rigorous and reflective science learning. Many researchers have urged the adoption of more authentic inquiry-based pedagogies to enhanced science learning (Chinn & Malhotra, 2001; Singer, Marx, Krajcik, & Chambers, 2000; White & Frederiksen, 1998).

In recent years, there has been an effort to develop reform-oriented and inquiry-based early science instruction. Examples of such programs include the Head Start on Science and Communication Program or HSSC (Klein, Hammrich, Bloom, & Ragins, 2000), the ScienceStart! Program (French, 2004), and Preschool Pathways to Science or PrePS© (Gelman & Brenneman, 2004). Although research efforts are under way to develop and deliver innovative preschool/kindergarten science curricula, there is a dearth of studies that document science-specific learning outcomes from such projects. Metz (2004) has noted that while many reform-oriented science curricula purport to teach scientific inquiry in "developmentally appropriate" ways, the issue of what constitutes a developmentally appropriate curriculum is itself open to debate. Metz notes that attempts to articulate developmentally appropriate standard of science learning for young children often result in a reduction of scientific inquiry to a set of fragmented and discrete "process" skills such as "making observations." She suggests that standard interpretations of developmental appropriateness may underrepresent children's capacities for science learning, especially with appropriate contextual support.

The research described in this study is part of the SLP, a federally funded project to enhance science teaching and learning in public kindergarten classrooms. We view science learning as a process of domain-specific knowledge construction. This view is grounded in research on human cognition and cognitive development (Brown, 1990; Carey & Spelke, 1994; Gelman & Brenneman, 2004). Domain-Specific perspectives share with classic developmental theories, the belief that children are active learners (Bruner, 1996, Piaget, 1955; Vygotsky, 1962). However, domain-specific approaches assume that learning in conceptual domains such as science and mathematics is characterized by the development of distinct domain-specific conceptual structures and processes. One implication of the domain-specific view of conceptual development is that instruction should focus on helping students acquire the core ideas and ways of thinking that are central to a particular domain of knowledge. For example, a recent National Research Council report advocates that the nation's science education standards should be organized around "big ideas" in a scientific discipline (Smith, Wiser, Anderson, Krajcik, & Coppola, 2004).

In addition, we view science learning as socially negotiated and situated in specific cultural contexts and practices (Boyd & Richerson, 2005; Brown, 1997; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Greeno, 1998; Rogoff, 1990; Roth, 2005). These perspectives are consistent with scholarship in the area of science studies, which suggests that scientific knowledge and practice are grounded in and shaped by particular sociohistoric contexts (Giere, 1988; Knorr-Cetina, 1999; Kuhn, 1962, 1977; Laudan, 1990; Thagard, 2003, 2004).

The SLP curriculum reflects several design principles for inquiry-based pedagogy that are recommended by a national panel of experts (summarized by Duschl and Grandy, 2008). According to Duschl and Grandy, there is consensus that inquiry-based science instruction should help students integrate three inter-related dimensions of science learning: (a) cognitive dimensions, which include the concepts of science and processes of scientific inference, (b) epistemic dimensions or frameworks for evaluating scientific knowledge, and (c) social dimensions or an understanding of sociocultural practices that shape how scientific knowledge changes over time. Duschl and Grandy recommend that these inter-related dimensions of science be taught as part of extended inquiry units.

The instructional approach used to achieve these ends is that of guided inquiry (Brown & Campione, 1994; Magnussen & Palincsar, 1995; White & Frederiksen, 1998). The design of SLP science activities for children is meant to capture key features of science as a set of cultural practices in ways that are accessible to kindergarten students. We realize that the above characterization both of science and of pedagogy is fairly broad and open to many different interpretations. It is not our intention here to debate the relative merits of the many diverse views of the nature of science and scientific inquiry as our study was not designed to test or evaluate these perspectives. Instead, we will first sketch out the notion of scientific inquiry that guides our work and then discuss how this view relates to the instructional practices of SLP.

Characterizing Scientific Inquiry

Following Giere (1988, 2002, 2004), we view science as process of articulating, testing, evaluating, and refining or revising models of the world. Giere suggests that knowledge in various domains and subdomains of science such as nuclear physics or geology is realized primarily in terms of families of models that represent theoretically important aspects of the external world. Theoretical models selectively represent features and relationships of things in the world (Giere, 2004). According to Giere, scientific hypotheses specify empirically testable similarities between our models and the natural world. Hypotheses also specify ways in which various models within a domain relate to each other. Scholars such as Suppes (1960, 1962) and Woodward (1989) have proposed that theoretical models are not evaluated directly against an external reality but rather indirectly through models of experimentation and models of data. Investigation models specify procedures for empirically evaluating theoretical models and include knowledge of design, as well as instrumentation and measurement (for instance, the use of placebos and “double blind” designs for investigating the therapeutic value of drugs). Data models specify ways of representing features and relationships among observational phenomena that provide the means for evaluating theoretical models (e.g., a simple model of data might be to graph the observed frequencies of two distinct outcomes across several runs of an “empirical test” relevant to some theoretical model).

What should be clear from the above discussion is that we reject any rigidly hierarchical view of scientific knowledge and inquiry. Given the debates about the meaning and utility of terms such as “theories” or “laws” in the history and philosophy of science (Cartwright, 1983, 1999; Giere, 1988; Kuhn, 1962; Laudan, 1990), we do not emphasize such distinctions in the context of SLP instruction. Nor do we view scientific inquiry as a purely hypotheticodeductive process in which hypotheses are logically deduced from the laws or axioms of a theory and verified against inductive support form empirical observations. In fact, many scholars have noted that in the routine practice of science, investigations are rarely about “testing” theories. Scientists may conduct investigations to extend or apply known models to new cases or problems (Kuhn, 1962; Laudan, 1990; Samarapungavan, Westby, & Bodner, 2006) or to develop and try out new techniques (Giere, 1988).

Earlier, we noted that SLP science activities are designed to capture features of science as a set of cultural practices for young children. We will now sketch out what we mean when we refer to science as a set of cultural practices. Many scholars have described the sociocultural dimensions of doing science (Giere, 1988; Knorr-Cetina, 1999; Kuhn 1962, 1977; Laudan, 1990). Although there is substantial disagreement among the scholars cited above on certain issues such as the merits of a realist stance in science and whether the epistemic norms of science are truth tropic (i.e., leading toward truer approximations of the real world), there is a general agreement that sociocultural practices of science provide for the co-construction, evaluation, and revision of shared knowledge and that consensus on the interpretation of empirical data plays a key role in this process.

Members of a community of practice share cognitive resources (Giere, 1988) such as a problem space (a representation of common or core problems that are the target of investigation), knowledge of representational conventions (e.g., representational formats such as images, diagrams, and mathematical models), knowledge of important domain models (e.g., Mendellian models of inheritance in biology), techniques for data collection and analysis, and epistemic norms (criteria or heuristics for evaluating the adequacy of knowledge). Scientific discourse among members of the community, both formal and informal (e.g., peer-refereed publications, professional conferences, and discussion among members of a research group) plays an important role in shaping the public or intersubjective dimensions of science both in terms of the content and the processes of science (Giere, 1988; Knorr-Cetina, 1999).

Novices who aspire to become members of a community of scientific practice must undergo a process of acculturation. Some aspects of scientific acculturation are institutionalized. Individuals who wish to become scientists must typically undergo formal education and training to acquire cognitive resources necessary for successful practice. However, other aspects of acculturation are informal in that they are not explicitly taught but rather learned informally as novices interact with more expert members of the scientific community (Samarapungavan, Westby, et al., 2006). The SLP project might be viewed as an early initiation of young children into a process of scientific acculturation. We will now turn our attention to the principles of guided inquiry as a framework for our pedagogical design.

Designing Inquiry for Young Children: A Guided Approach

The guided inquiry approach is an attempt to replicate some of the constructive features of science as a set of cultural practices in the design of science-learning environments for children (Brown & Campione, 1994; Magnussen & Palincsar, 1995). The science-learning environment in the current study was designed to afford children with opportunities to engage in the practices of science by constructing, evaluating, and refining or re(constructing) models of the natural world.

One of the key issues in guided inquiry is to select an investigative context that allows children to create meaningful new knowledge. To ensure that the children's inquiry was productive, we had to pick a topic that was amenable to investigation given the cognitive resources that children brought to the task. Furthermore, we had to consider the cognitive resources that could be developed "in situ" with appropriate instructional support or guidance to help children get the most out of their investigations. This instructional support and guidance took many forms. Some of this guidance was "hard-wired" into the instructional design. For instance, such factors as the choice of topic, the observational environment, and the use of certain tools and artifacts in the conduct of the investigations were predetermined by the researchers in consultation with the collaborating classroom teachers. Other forms of support and guidance were more contextual and introduced by the classroom teachers when they deemed necessary. These included modeling aspects of inquiry for children when needed, scaffolding children's model construction, and their science discourse about their models through, hints, questions, and clarifications provided by the teacher, and scaffolding children's understanding of the processes on scientific inquiry. We will elaborate on these issues more in the discussion of results. Before we describe the methodology in detail, we will provide a brief overview of the study.

Description of the Study

This research examined the nature and scope of kindergarten students' science learning from an inquiry unit in which they investigated the life cycle of the monarch butterfly. Our goal was to provide descriptive data on children's science learning as they engaged in their investigations. The primary data source for these descriptions was an electronic portfolio assessment that was developed as a research tool to provide quantitative data on what children learn from their inquiry. A second source of data was an objective researcher-designed instrument called the SLA, which was administered to children in the SLP intervention who completed the inquiry unit and also to a comparison group of kindergarten students that was similar in demographic characteristics but did not get dedicated science instruction. The comparison group provided baseline information about children's science concepts in the absence of science instruction to provide a sense of what the intervention group learned from the inquiry unit. The portfolio and SLA assessments are described in more detail in the Methods section.

Choice of Topic. We chose biology as our starting point primarily because developmental research suggests that even before they begin formal schooling, young children have formed biological concepts which allow them to reason causally, make predictions about biological phenomena, and categorize natural kinds (Ahn et al., 2001; Greif, Kemler Nelson, Keil, & Guitierrez, 2006; Inagaki & Hatano, 2004). Children also have access to many biological phenomena through everyday experiences with plants and animals in their environment. The general conceptual terrain that we were interested in was children's understanding of living things and their characteristics. The specific focus of investigation was the life cycle of the monarch butterfly.

Developmental research indicates that although young children differentiate between living and nonliving things, their concepts are often simple and underspecified in addition to being normatively incorrect (i.e., different from the corresponding scientific model). For instance, Inagaki and Hatano (2004) found that while preschoolers thought of growth over time as a unique property of living things (plants and animals), they tended to represent biological growth simply as a process of "getting bigger and bigger." Such findings indicate that there is ample room for conceptual change in children's biological concepts of growth and development.

Research of this nature led us to select biological growth and development as the conceptual focus of the current inquiry unit. One advantage of focusing on biological growth and development is that children could actually observe the (external) morphological and behavioral changes that occur in the course of growth and development over a period of time. The extended observational time frame provided children with opportunities to articulate, elaborate, evaluate, and revise their models of growth and development as they coordinated their ideas with observations of a real life cycle. To understand the processes of biological growth and development, children must also develop an understanding of biological structure and function (physical and behavioral characteristics of species and their role in meeting the species' biological needs for survival and reproduction) as well as of biological adaption (the ways in which species "fit" into and interact with their environment). Thus, the topic allows for the construction of rich biological knowledge.

The decision to use the monarch life cycle as the context for children's investigations was based on several pragmatic and pedagogical considerations. In preliminary meetings, the collaborating teachers had mentioned the life cycle of the butterfly as one of the topics they had taught before and were interested in teaching. From a practical perspective, working with the teachers to develop inquiry units that met mandated state standards was very important to securing their collaboration in the project.

Pedagogically, the time frame for the monarch life cycle, which unfolds over a period of approximately 6–8 weeks, provided children with opportunities for sustained inquiry. In addition, the opportunity to observe that the monarch butterfly goes through several stages of metamorphosis in its growth and development should provide a strong epistemic press for children to revise their initial simplistic models of biological growth and development (i.e., parents produce offspring that are their smaller-scale replicas and that will grow over time to adult size).

The empirical framework for the children's investigations was that of (semi) naturalistic observation. The observation of patterns of growth and development of monarch larvae on live milkweed plants provided the empirical underpinnings for the investigation. In addition, the overall framework for the investigation was provided for the students by the teacher. Thus, the children were not involved in the design of the investigation. However, the investigative design did provide children with opportunities to decide what kinds of questions they wanted to explore, what they wanted to observe and record, and what conclusions they drew from their investigations. Developmental research indicates that while young children may not possess the cognitive resources of adults or scientists when it comes to designing controlled experiments and evaluating the fit of models to data (Klahr, 2000; Kuhn & Dean, 2004; Masnick & Klahr, 2003; Schauble, 1996) they can revise their concepts in the face of significant new evidence (Carey, 2004; Carey & Sarnecka, 2006; Gopnik et al., 2004; Metz, 2004). Details of the study will be described in the next section.

METHODS

Research Questions

Two broad research questions (each followed by more specific subquestions) guided the design and analyses in this study. These are listed below:

1. Can kindergarten children engage in the processes of inquiry and develop a functional understanding of inquiry?

    a. Do kindergarten children use their biological knowledge to generate questions and predictions that can be addressed by empirical evidence?
    b. Can kindergarten children gather empirical evidence (observe and record data) during investigations?
    c. Do kindergarten children use empirical evidence to elaborate or revise their models during the course of investigations?
    d. Can kindergarten children communicate about their investigations to others?

2. How does kindergarten children's biological knowledge develop and change through their participation in the inquiry activities?

   a. Do children attend to the relationship between structure and function in biological adaption? For instance, do they represent various ways in which specific species such as the monarch butterfly are adapted to their environment?
   b. Can children model the life cycle of a monarch butterfly, representing the key stages of its metamorphosis (egg, caterpillar, chrysalis, and butterfly)?

Design

The primary focus of this study was to gather descriptive data on science learning from children in the inquiry (INQ) or intervention group. The INQ group consisted of four public school kindergarten classrooms that implemented the inquiry unit on the life cycle of the monarch butterfly. The primary data source for children's science learning in the INQ group was portfolio evidence. For each child in the INQ group, comprehensive samples of work during inquiry activities were collected to provide descriptive data on learning. Secondary data on learning were gathered by administering the SLA (Samarapungavan, Patrick, et al., 2006; Samarapungavan et al., 2007). The SLA was administered to the INQ group after they had completed the inquiry unit. It was also administered to a second group of students, the comparison (COMP) group. The COMP group consisted of two classrooms in a different public school (from the same school district as the INQ group) that did not receive any targeted science instruction as part of their kindergarten curriculum.

Participants

This study was conducted in a midwestern, suburban public school district. There were 100 participants in the study. Primary data were collected from 65 INQ group children, in four kindergarten classrooms, attending the same public school. The classrooms were taught by three teachers (one teacher taught two classrooms). Eighty-two children were enrolled in the INQ classrooms at the beginning of the science unit. We obtained informed consent for 71 (86.5%) of those children. However, we obtained complete data (portfolio evidence and SLA scores) for 65 children, because six children moved from the school before the end of the unit.

The COMP group consisted of 35 children who attended two kindergarten classrooms in a second public school drawn from the same school district as the INQ group. Fifty-two children were enrolled in two kindergarten classrooms, and we obtained informed consent for 35 (68%) of them prior to SLA administration. SLA data were collected for all 35 children. To control for general instructional effects, both the intervention and the comparison groups were assessed in the same 2-month period around the middle of the academic year.

Demographic information for both groups is provided in Table 1. Both groups were diverse in terms of gender and race and ethnicity. A significant number of children in both groups (54% in the INQ group and 60% in the COMP group) received free and reduced lunch.

Description of Intervention

The premise behind the SLP intervention is that early scientific literacy is facilitated in everyday interactive contexts that provide opportunities for cognitively guided learning and

TABLE 1
Demographic Data for INQ and COMP Groups

	INQ Group		COMP Group	
Demographic Characteristics	Frequency	%	Frequency	%
Gender				
Female	31	48	13	37
Male	34	52	22	63
Race/ethnicity				
Caucasian	34	52	25	71
African American	7	11	4	12
Hispanic	20	31	0	0
Others	4	6	6	17
Free-reduced lunch				
Receives free-reduced lunch	35	54	21	60
Self-paying	12	18	13	37
No data[a]	18	28	1	3

COMP = comparison; INQ = inquiry.
[a]Children for whom the school had no free lunch data were those who did not eat lunch at school.

classroom discourse involving concepts of science. The instructional goals for the inquiry unit are listed in Table 2. There are two related clusters of goals: Goals 1a–1d (see Table 2) relate to children's functional or enacted understanding of the processes of scientific inquiry. Goals 2a–2b relate to children's understanding of key ideas in biology instantiated through the monarch life cycle. These curricular goals are consistent with the content standards for kindergarten science learning specified in three standards documents: (a) the National Science Education Standards (National Research Council, 1996), (b) the Benchmarks for Scientific Literacy (American Association for the Advancement of Science, 1993), and (c) Indiana's Academic Standards: Kindergarten Science (Indiana Department of Education, 2003).

Our theoretical perspective described above shapes our interpretation of what it means for young children to understand the processes of scientific inquiry. We examine children's

TABLE 2
Instructional Goals for the Inquiry Unit

1. Scientific Inquiry Processes
   (a) Can use biological knowledge to generate scientific questions and predictions.
   (b) Can observe and record data relevant to their investigations.
   (c) Can extend or revise their knowledge through their investigations.
   (d) Can communicate about their investigations and knowledge.
2. Life Science Knowledge
   (a) *Structure and function*: Understand that plants and animals have specific structures and traits (e.g., physical and behavioral characteristics) that help them adapt to their environment and to survive, grow, and reproduce: Can generate examples of ways in which specific species, such as the monarch butterfly, are adapted to their environment.
   (b) *Understand that living things grow and develop*: Can model the growth and development of the monarch butterfly.

functional understanding of inquiry as manifest in their ability to engage in scientific investigations that help them to articulate and revise their models of the world. Our interpretation draws on Chinn and Samarapungavan's (2005) notion of enacted epistemologies as functional understandings that are manifest in the practical contexts and activities of knowledge articulation and evaluation. For example, in evaluating children's understanding of scientific inquiry, we are not interested in whether they can define or describe what a prediction means or what constitutes a scientific question. Rather, we want to determine whether children can generate scientifically meaningful questions and predictions in their own investigations and whether they can identify instances of scientific questions and predictions embedded in practical or concrete scenarios.

The instructional materials and activities used in the intervention were developed collaboratively by the researchers and the participating teachers. As noted earlier, the teacher's interest in and prior experience with teaching children about biological growth and development through the life cycle of the butterfly contributed to our choice of topic. The intervention teachers volunteered to participate in our study because they were interested in learning about inquiry-based science instruction. They were unfamiliar with inquiry-based teaching at the start of the project. Prior to implementation, members of the research team met several times with the teachers to share theoretical perspectives, develop a framework for the implementation of the unit, to suggest inquiry activities, and to incorporate the teachers' suggestions into the unit. We did not formally script the inquiry activities because we wanted teachers to maintain ownership of the activities and to be able to explore learning trajectories that arose naturally from the instructional context.

The teachers were provided with a teacher guide that explained the instructional goals of the unit and contained brief descriptions of intervention activities (in sequence) with examples of ways in which teachers might introduce the activities and scaffold children's discussion and learning. The teacher guide provided teachers with a brief outline of relevant biological information for each activity. We also provided the teachers with links to Web sites where they could find additional information on monarch butterflies. Each INQ teacher was assigned a classroom assistant (a member of the SLP project team) to help with the implementation of the intervention. After we had determined a sequence of activities, the intervention teachers and classroom assistants attended a preintervention workshop (developed by members of the research team) to learn how to implement these activities. During the workshop, participants experimented with intervention materials and activities, taking on the roles of teacher and student to get a sense of how the activities might work.

Once the intervention began, members of the research team met with INQ teachers once a week after school for half an hour to discuss unit implementation, record teachers' suggestions for future implementation, and address any concerns that arose during the course of implementation. In addition, the teachers and classroom assistants used e-mail communications to address ad hoc issues or concerns that arose during instruction. The e-mail communications typically took the form of requests for additional content information. For example, in one classroom, a discussion of ways in which living things responded to their environment led one child to ask whether all bears hibernate. The teacher asked her classroom assistant to forward the question via e-mail to members of the research team who were able to provide an answer.

The INQ classrooms used science activities developed as part of SLP to explore the properties of living things and the theme of growth and development through the life cycle of the monarch butterfly. The INQ teachers had not taught any science prior to the start of the inquiry unit. The inquiry unit was implemented about 3 weeks after the school year started and consisted of integrated inquiry and literacy activities. The children in each class engaged in unit activities for a period of 5 weeks (2 days per week). The length of each session ranged from 30 minutes to 1 hour.

Through the course of the inquiry unit, the teacher read thematically related nonfiction books (on living things, insects, life cycles, etc.) with the children using dialogic reading strategies (Whitehurst et al., 1999). A member of the research team with expertise in developmentally appropriate reading practices for young children reviewed the books to ensure that the language (vocabulary, syntax, etc.) was appropriate for young children with emerging literacy skills. A second member of the research team with expertise in science learning reviewed the books for factual accuracy. This initial set of books was then sent to the teachers who also reviewed the books based on their prior teaching experience and made recommendations for the final selection of books. The readings helped children acquire background knowledge relevant to their investigations and also helped them extend and systematize their knowledge through the course of the inquiry unit. Unit activities were grouped in three broad phases: preinquiry, inquiry, and postinquiry, which are described below.

Preinquiry Activities

These activities served to activate prior knowledge, introduce the purpose of the investigation, and provide children with the task framework. Each child received his or her own notebook and recorded questions or predictions about butterflies. The science notebook entries were typically created by the child with scaffolding from an adult (the teacher or assistant). The child decided what entries to make and was free to draw, paste digital photographs of observations, write (using invented spelling if needed), or to ask an adult to assist with writing. In cases where the adult helped the child write entries, the adult wrote down what the child said verbatim. This is consistent with recommended instructional practices for young children in emergent literacy contexts provided by the National Association for the Education of Young Children (1998). During the preinquiry phase, teachers read a variety of books with the children such as *Living Things* (Trussel-Cullen, 2001) and *Can You See an Insect?* (James, 2001). A brief outline of the preinquiry lessons follows:

Activity 1: What Is Science. This lesson was conducted as a whole-class discussion. In this lesson, teachers introduced the idea of science as the study of the world around us. The teachers led children in a discussion of what it meant to be a scientist and to do science. Excerpts 1 and 2 taken from classroom discourse of a single lesson illustrate Activity 1. Both excerpts are from a whole-class discussion. The children were seated in a semicircle on a carpet facing the teacher. In this lesson, Teacher 3 began by asking children what they think science is. Excerpt 1 illustrates the children's responses to this initial question. Teacher 3 then began the focal activity of the lesson to help children understand science as a way of investigating things around them. She passed around a tulip bulb and asked the children to try and figure out what it is. Excerpt 3 illustrates the nature of this discussion.

Excerpt 1: Activity 1—Classroom 3 (September 7)

Teacher 3:	Well, boys and girls, we are going to learn about something called science.
Ky:	(says something inaudible)
Teacher 3:	Oh, Ky wants to tell us what she thinks science means. What does it mean?
Ky:	It means that. . . means. . . that science someone?

Teacher 3: That what?
Ky: Science someone.
Teacher 3: Science someone. Anybody else, what do you think science is? N?
N: Work.
Teacher 3: When you work.
N: No when you (unclear if child says work or look) . . .

Excerpt 2: Activity 1—Classroom 3 (September 7)

C: It's a nut, it's a nut.
E: It's a nut.
Teacher 3: Ok, well listen to L. What did you say?
La: You could try to guess.
Teacher: Try to guess. That is called making a pre::::::diction. Can you say, 'making a pre::::::diction'?
(Children): Pre::::::diction.
C: Nut! Nut! Nut!
Teacher 3: You can guess, you can ask questions, or you can be like some people who saw a little bit and they say that it is a nut. Guess what? You may think it's a nut, and somebody else might think that it is something else. (Several students continue to say that it is a nut)
Le: It looks like an onion.
Teacher 3: Ok, so how does it look like an onion?
Le: Well, its shape and it has crust like that.
C: I saw an onion before but it wasn't small; it was big.
Teacher 3: Ok, my next question. How can we find out what it is?
C: It's an onion. You gotta think.
Teacher 3: But what if it's not an onion?
C: But it has a peel.
N: Because it's an onion?
Teacher 3: But what if it's not an onion? How do we find out about it? Ka?
Ka: It ain't an onion, 'cause it's hard.
Teacher 3: Huh, she said that she does not think it is an onion. Are onions hard?
Ka: No.
Le: It's an onion because if you push it really, really hard, it's squishy.
Teacher 3: Did you hear An? He has a different idea.
An: It's a potato!
Mo: A tomato.
Teacher 3: Somebody says a tomato.
C: It's a . . . Tomatoes are red.
Teacher 3: Ah. So is it a different color than a tomato.
C: It's brown and the tomatoes . . . the potatoes are brown.
Ka: ( )
Teacher 3: Ok, Ka, I like your thinking, what could we do with this to find out what it is?
Ka: It's clear. Think about it.
Teacher 3: Well we have been thinking. . .
Ky: We could bury it and wait for it to grow.
Teacher 3: Huh. Everybody stop! Say it nice and loud Ky.
Ky: Um. . . Bury it and let it grow.

Activity 2: Tools for Inquiry. This lesson started with a whole-class discussion of tools that scientists use for inquiry. The children then formed small groups (four to five children per group) to learn about two tools that they would use during their investigations (a ruler and a magnifying glass). An excerpt from classroom discourse for this lesson (Excerpt 3) is provided below. This lesson took place in the classroom of Teacher 2. The lesson began with a whole-class discussion. Children were shown a small capsule (a sponge) and asked to make guesses or predictions about what it was. The children then formed small groups. Each child was given a small capsule that turned into a sponge when dipped in water. The children used magnifying glasses and rulers to study the object. The excerpt is from one small group of five children (Ja, Jr, Ly, Mi, and S) working with the classroom assistant (CA2).

Excerpt 3: Activity 2—Classroom 2 (September 8)

CA2: OK, guys. So. We've talked about all of these tools we have. Right . . . Tools that scientists use. What's this called?
All: A magnifying glass.
CA2: A magnifying glass.
Ly: I've used those a hundred times.
CA2: Really! To do what?
Ly: To look at bugs and stuff. I've looked at bugs that tiny.
. . .
CA2: So if we take our magnifying glasses and look at our science project, what do you see? If you look at it with your magnifying glass?
Mi: It looks fuzzy.
. . .
Ja: Yeah.
CA2: What do you guys think?
Ly: I saw really tiny fuzzy things.

Activity 3: Introducing the Investigation. This lesson started with a whole-class discussion of insects. Children were asked to share what they know about insects. They were then told that they would be learning about butterflies. The teacher reminded them that butterflies are living things and asked them whether they could think of things they wanted to find out about butterflies as living things. If questions about the growth and development of butterflies did not emerge naturally, the teacher introduced or models questions about the growth and development of butterflies and elicited questions and predictions from children about butterflies and the butterfly life cycle. Children were introduced to science notebooks as tools for keeping track of their investigations.

Excerpt 4 illustrates the first part of Activity 3 in which children are introduced to the idea that scientists begin investigation by generating questions and predictions. Teacher 1 started the lesson with a discussion of living things and insects. She then reviewed the things that the children already know about butterflies by reading the ideas that the children generated and she had recorded on the idea board in a previous brainstorming session. In this segment of the lesson, the teacher encouraged the children to generate questions and predictions about caterpillars and butterflies. Her classroom assistant (CA1) helped to scaffold the children's discussion.

Excerpt 4: Activity 3—Classroom 1 (September 8)

Teacher 1: Butterflies. Now, today you are going to get the chance to <u>ask</u> a question? Or, make a PREdiction . . .
Teacher 1: Do you know what that is? That means that you are going to make a guess about something that the butterfly is going to do– or what the

caterpillar is going to do. We're going to think of something that might happen. Or if we have a question, . . . if there is something that we want to know . . .

Students: [[They fly. They eat. Colors]]

Teacher 1: (to SLP observers) We may get something or we may not. (laughs) Maybe I'm not probing enough, okay?

CA1: I want to know what baby butterflies look like.

Teacher 1: Excellent question!

CA1: I don't know what they look like.

Co: They're like this small (makes a gesture with his hand showing size).

Jo: They look like babies.

L: Do butterflies. . . um. . . in their mommy's tummy?

Teacher 1: What do baby butterflies look like?

Teacher 1: Okay. E! So we're going to write that down. Okay, that's a question that we could ask. (starts to write the question on the idea board)

. . .

L: Do butterflies. . . um. . . in their mommy's tummy?

Teacher 1: The butterflies are in the mommy's tummy? Okay. I would say that maybe that is a prediction. Okay? Not a daddy? In a mommy's tummy?

L: (nods) Yes.

Teacher 1: Okay. (writes on idea board) Butterflies, (pauses) Is that butterfly babies?

L: (nods) Yes.

Teacher 1: Okay, so should we put "butterfly babies"? Okay (continues writing) "are . . . in . . . the . . . mommy . . . mommy's . . . tummy!" Okay . . .

Teacher 1: All right, is there something else we want to ask about butterflies or caterpillars?

H: They stay in a place until they get colorful.

Teacher 1: Okay, they stay in one place until they get colorful. Okay, so you are making a prediction, aren't you? She says that they stay in one spot until they get colorful.

Inquiry Activities. These activities were a set of *small group* activities through which children conducted their investigations of the butterfly life cycle. They included asking questions or making predictions, thinking about what they would observe, collecting and recording data, and drawing conclusions from data. During the inquiry phase, children extended their knowledge of insects by reading books about the characteristics of insects, their structure, reproduction, adaptations to the environment and mechanisms of survival (e.g., James, 2001). A brief description of lessons in the inquiry phase follows.

Activity 4: Introduction of Observational Setting. The inquiry phase for the unit began by introducing the students to the butterfly garden, which was a large breeding cage containing live monarch larvae on large milkweed plants (the larvae were about 1 week old when they were introduced into the classroom). Children were asked to make predictions about how the larvae would grow and what they would look like as adults. The children also generated questions about the larvae that they could answer by observing them. Children recorded their questions and predictions in science notebooks. Excerpt 5 illustrates how children were introduced to the live caterpillars. Five children (Cr, De, Ly, Md, De, and S) are at the table with the breeding cage. They are working with the classroom assistant (CA2).

Excerpt 5: Activity 4—Classroom 2 (September 14)

CA2:	So today you guys, we are going to look at the caterpillars. They're on here (pointing to the plant at the center of the table), they're on these trees. Can you guys find them? Here, let me give you each a magnifying glass.
	(She hands the magnifying glasses out)
CA2:	Can you guys find the caterpillars? Do you know where they are?
	(Students begin to study the tree with their magnifying glass to find the caterpillars)
Cr:	(Pointing to a leaf) I can see one.
CA2:	Where? I don't see any caterpillar there.
De:	(Pointing) I see a caterpillar.
CA3:	You see a caterpillar, where?
Md:	(Looking at the caterpillar De pointed to through her magnifying glass) Yeah, a big one.
CA2:	Oh! Wow! Look at that, it's huge.
S:	(Looking at the milkweed plant) I see a caterpillar
CA2:	Do you guys see it?
Students:	Yeah
CA2:	What about the other one? (Pointing to a different caterpillar) I think there is one on here too. Do you guys see it?
Ly:	(Looking through her magnifying glass) I see one here.

Activity 5: Observing and Recording Growth and Development. This was a recurring activity that children engaged in twice a week until the adult butterflies emerged. Each classroom completed four or five separate lessons in which observations were made, recorded in science notebooks, and discussed. The children kept records of the monarchs' growth and development in their science notebooks using a combination of drawings, photographs taken with digital cameras, and writing. Children also learned about the external anatomy of the monarch through different stages of metamorphosis and how the monarch was adapted to its habitat. Excerpt 6 illustrates how children learned about the monarch's adaptations during Activity 5. In this excerpt, the children were in a small group, seated in a semicircle on a carpet facing Teacher 3. They discussed what they learned from their observations of the monarch caterpillars the previous day.

Excerpt 6: Activity 5—Classroom 3 (September 15)

C:	Camouflage!
Teacher 3:	Camouflage? Is that a way they hide? Yes?
Mo:	On plants you don't see them because they're the same color.
Teacher 3:	Do they what? (To L who started to say something)
Le:	Do they eat?
Teacher:	Do they eat? What do they eat over there now? (Points to table with live caterpillars)
C:	(Gets up and looks in the direction of the caterpillars) They're eating the leaves!
Tr:	Milkweed plants. . .
Teacher 3:	Have you thought of a question yet? (To Tr)
Tr:	How do they get out?
Teacher 3:	How do they get out? You mean the net (points to the breeding cage)?
Tr:	(nods)

Another excerpt (Excerpt 7 from Classroom 2) is provided to illustrate how children conducted investigations of caterpillar growth. The students are working with two classroom assistants, CA2 and CA4, to take a set of measures of caterpillar length to compare with a set of measures they had recorded the previous day.

Excerpt 7: Activity 5—Classroom 2 (September 21)

CA2: This is the string that we had yesterday; remember we measured the caterpillars with the string? We're going to do that again.
(pause) (CA4 passes out lengths of string to each child)
CA4: Does everybody have a string?
Children: [[Yes]]
CA2: So take your string, find one of the caterpillars.
(Students are crowded around the milkweed plant observing and trying to take their caterpillar measurements) . . .
CA2: (To J) Stand up over here, let's measure it, then we have to . . . Don't stand on the chair you guys. (To Cl who is standing on his chair to try and measure a caterpillar on a high branch of the milkweed plant which is on the table) I don't want you to stand on the chair; you might fall and get hurt. Okay?
Cl: (Pointing to a caterpillar) He is five inches.
CA2: Five inches? How do you know?
A: This is two, two inches (pointing to her paper). This caterpillar (pointing to the caterpillar on the plant) this caterpillar is two inches.
CL: (Realigns his string)

Postinquiry Activities. These were *small group* and *whole-class* activities that enabled children to communicate and share the results of their investigations and identify unresolved issues or questions. These activities provided children with an opportunity to reflect upon and communicate what they had learned about the butterfly life cycle. During postinquiry, the children read *From Caterpillar to Butterfly* (Heiligman, 1996).

Activity 6: Communicating About Investigations. Children worked in small groups to discuss, reflect upon, and summarize what they had learned. They also created posters showing their models of the monarch life cycle to share with the class. Excerpt 8 illustrates how children reflected upon what they had learned. In this segment of Activity 6, children in Classroom 2 were working in small groups to describe what they learned from their investigations and summarize it in their science notebooks. The excerpt is from a small group working with the classroom assistant, CA2.

Excerpt 8: Activity 6—Classroom 2 (October 6)

CA2: All right, so what do you guys notice? Let's talk about the butterflies, Cl and J, what did you guys learn? Tell me.
Cl: We learn about butterflies . . .
Cl: We learn to be careful and not scaring them.
CA2: Oh ok, that's good, Cl, what do you want me to write in your book? That you learned?
Cl: I want you to write about the chrysalis.
CA2: What do you want me to write about the chrysalis?
Cl: That it was black and you could see the butterfly inside.
CA2: (Starts writing what Cl said in his science notebook)

A: Yeah, we can see a little part of the wing and then it was clear.
Cl: (To A) Stop, I'm trying to talk.
CA2: Yes, let Cl talk, ok?
Cl: Then I said it was going to be a butterfly.

The Teacher's Role. The role of the teachers during the intervention was to facilitate and support children's learning from the inquiry units. INQ teachers scaffolded children's learning by asking questions, providing hints and reminders to children through the process of investigation, and modeling skills for children as needed. The teachers also helped children communicate by encouraging small group and whole-class discussion and developing a system for students to share what they have learned in each inquiry cycle. One example of the teacher's role can be seen in the excerpt of classroom discourse provided in Excerpt 2, which illustrates how the teacher supports the children's co-construction of the idea of an empirical test for divergent hypotheses through skillful questioning. A second example (see Excerpt 7) illustrates how the classroom assistants (CA1 and CA2) scaffold the measurement activities of children, helping them realign their misaligned lengths of string against a measuring scale, and focusing their attention on comparing measurements across two time points through questioning.

Science Discourse. One important aspect of the inquiry activities was the emphasis on science discourse. Children were encouraged to generate, compare, argue about, and to deliberate upon how they might reach consensus on ideas throughout their investigations. INQ teachers helped children learn the vocabulary of science contextually by introducing and modeling key terms such as "predict," "question," "observe and record," "conclude," and "communicate" during the flow of relevant activities and by explicitly using these terms to describe what children said or did during inquiry. Excerpt 4 illustrates how one teacher helped her students understand the difference between questions and predictions contextually.

The teachers supported the children's construction of knowledge through the use of questioning and by drawing attention to and making salient, key ideas that children generated during discourse. Excerpts 2 and 6 illustrate an important aspect of science talk generated during the intervention, namely that children discuss science with each other, and not just with the teacher. Consider for instance, the dialog in Excerpt 2 between the children Le, C, N, Ka, and the teacher about whether the object under consideration (tulip bulb) is or is not an onion. Children used observations and prior knowledge to construct arguments about why the object in question either was (shape, peel, etc.) or was not an onion (too hard, etc.). Excerpt 6 illustrates how children co-constructed knowledge about the characteristics of butterflies as living things through discourse. The children's questions and comments about caterpillars and butterflies were meaningful and displayed their understanding of important characteristics of living things such as their need for food, their habitats (as reflected in *Tr's* question about how the caterpillars could escape the *unnatural* habitat of the breeding cage), and adaptive mechanisms for self-protection.

One of the features of SLP science activities and discourse is that the cognitive skills involved in inquiry such as asking questions or using empirical data to make inferences are not artificially fragmented and serialized across the three phases of the inquiry cycle. Children were not discouraged from posing new questions as they entered the inquiry phase and empirical observations were supported by the teacher in the context of the questions that emerged. For example, in Excerpt 6 when Le wanted to know what caterpillars eat, the teacher asked the children to look and find out.

Science Activities in COMP Group. The kindergarten teachers in the comparison group said that they did not teach dedicated science lessons because of the heavy focus on literacy and numeracy, although they included topics such as animals and seasons in the course of classroom literacy activities. Three baseline lessons were videotaped in each COMP teacher's classroom to document instructional style and developmental appropriateness of instruction. Both lessons were nonscience lessons. Each teacher conducted a whole-class lesson followed by individual seat work. In individual interviews, the teachers said that this was fairly typical because they had large class sizes and found it difficult to organize small group activities for children in the absence of extra help. Although each teacher engaged the children in responses during whole-class activities, for example, through direct questions and sing along/recitation activities, both teachers also engaged in a fair amount of "telling" or direct instruction.

DATA SOURCES

Portfolio Evidence

The primary source of evidence for children's science learning from the inquiry unit comes from the unit portfolios. Portfolio evidence was collected and evaluated for the 65 INQ children who participated in the inquiry unit on the life cycle of the monarch butterfly. An electronic portfolio system was used to collect and evaluate evidence of children's learning through classroom inquiry activities. The two types of data entered into the portfolio database are described below.

Artifacts. Each child's portfolio is an electronic record comprising all the artifacts that he or she produced during the course of each inquiry unit. While such a comprehensive approach to collecting portfolio evidence is clearly not feasible for teachers in the course of regular instruction, funding for the SLP project allowed us to build a comprehensive portfolio database for research purposes. Portfolio evidence for each child included scanned copies or digital photographs of drawings, posters, or science notebook entries produced during the course unit activities. The artifacts were typically collected and digitized immediately after the completion of the relevant activities. They were returned to the children within 2–3 days. Although, our goal was to collect all artifacts produced, there was some loss of data. For example, occasionally there was an individual page missing from a child's digitized science notebook. However, because of the large volume of portfolio evidence available for each child, such missing data were unlikely to have a significant influence on portfolio evaluations.

Videos and Transcripts. All intervention activities in each INQ classroom were videotaped and transcribed using the transcription methods developed by Psathas (1995). Because our primary interest in this study was in the cognitive analysis of science learning, we included brief contextual descriptions of relevant classroom settings and activities for each transcription. The videos and transcripts were stored electronically in our database (categorized by class, activity, etc.). We could search for individual children's contributions to classroom discourse for each dimension of our portfolio evaluations by running a name search for each child within the transcripts of each activity. After we identified potential sources of evidence, we would retrieve the relevant video files and watch them to get a fuller sense of the context. There is also some loss of videotape data. Occasionally, a child was not clearly audible or visible on tape. The audio-recording failed during the videotaping of one

30-minute segment of a preinquiry activity in one of the intervention classrooms, leaving us with no record of the discourse for that segment of the activity. Again, the volume of portfolio evidence available mitigated the impact of these specific data losses.

Portfolios Ratings

A portfolio rubric was developed to evaluate the children's portfolio evidence. Table 3 lists the specific aspects of knowledge/skill that were evaluated for this unit. Items P1-P4

TABLE 3
Portfolio Ratings: Frequency and Percentage of Scores by Item

	Scores							
	3		2		1		0	
Items	Frequency	%	Frequency	%	Frequency	%	Frequency	%
P1. Generates questions/makes predictions about the natural world	36	55.4	26	40	2	3.1	1	1.5
P2. Observes and records data during investigations	44	67.7	17	26.2	3	4.6	1	1.5
P3. Uses empirical evidence to extend, elaborate, or revise knowledge	7	10.8	36	55.4	13	20	9	13.8
P4. Communicates about investigations to others	35	53.8	20	30.8	8	12.3	2	3.1
P5. Can describe physical and behavioral characteristics of the monarch butterfly	22	33.8	31	47.7	9	13.8	3	4.6
P6. Can describe how the monarch butterfly is adapted to its habitat	10	15.4	37	56.9	13	20	5	7.7
P7. Understands the growth and development of the monarch butterfly	37	56.9	24	36.9	2	3.1	2	3.1

Note: Scores: 3 = highly proficient; 2 = proficient; 1 = somewhat proficient; 0 = cannot determine/missing data.

in Table 3 represent understanding of the processes of scientific inquiry such as the ability to ask questions about the natural world, to gather and use empirical evidence, and to communicate about science. They provide information on how well the children met instruction goals 1a–1d outlined in Table 2.

P1 indicates the children's ability to generate biologically relevant questions and predictions about living things in general, as well as about monarch butterflies, in the course of their investigations. By biologically relevant questions, we mean questions that address core themes in biology such as structure and function, adaptation, and growth and development. The questions and predictions could be general (e.g., "What do living things eat?" or "Everything would die without water.") or specific (e.g., "What do caterpillars eat?" or "The caterpillar will sleep for three hours.").

P2 is an indicator of the children's ability to conduct empirical observations and record data relevant to their investigations.

P3 is an indicator of the extent to which children were able to use empirical data to extend, evaluate, or revise their biological knowledge.

P4 is an indicator of the children's ability to communicate about their investigations verbally or through drawings and pictures. For example, in Excerpt 7 in recounting what he learned from his observations, Cl clearly refers to observational data.

P5 reflects children's understanding of biological structure and function in the monarch butterfly. For example, children can recognize and name the functions of the monarch's physical characteristics such as its legs, antennae, mouth, eyes, and gender-specific coloration (adult males have different wing coloration, comprising two black dots on the hind wings and thinner vein pigmentation overall, from females).

P6 reflects children's understanding of how the monarch is adapted to its habitat (e.g., monarch larvae need milkweed plants to feed on, monarch caterpillar coloration provides camouflage against the habitat of the milkweed plant, and so forth).

P7 indicates children's understanding of monarch growth and development, that is, it undergoes key stages in its metamorphosis from egg, to caterpillar, to chrysalis, to the adult butterfly).

Each child was rated on each item in the portfolio rubric by a trained rater who was a member of the research team using the following scale:

0 *Cannot determine/Missing data*: The child did not participate in unit activities (e.g., was not in class during unit activities relevant to target) or the child was present during unit activities did not generate any artifact or discourse evidence relevant to the target.

1 *Somewhat Proficient*: The artifacts are incomplete or unclear and the child does not generate relevant science discourse or artifacts without a great deal of explicit modeling and direction from the teacher.

2 *Proficient*: There are at least two clear examples of evidence from the child's artifacts (e.g., a page from a science notebook) or from classroom science discourse indicating that the child can generate the target knowledge/skill with *some* scaffolding or prompts from the teacher.

3 *Highly Proficient*: Same as "2" but the child can generate the knowledge/skill independently, with minimal scaffolding/prompts from the teacher.

For the portfolio ratings, we coded children's talk or artifacts, as belonging to a single segment or unit of evidence if they were (a) generated as part of a single activity or work sequence (e.g., recording observations on a given day, or making a poster about the life cycle of the butterfly), and (b) related to the same concept. The same segment could be used for ratings on multiple portfolio dimensions. To demonstrate how the coding scheme works, examples from the work of two children, Dr and Tr, are provided below.

Dr received a score of *somewhat proficient* (1) on P1 and P4. His performance on criteria P3, P5, and P6, could not be determined so he was given a score of 0 on these criteria. He rarely spoke up spontaneously during classroom science discourse and had to be prompted repeatedly by the teacher to participate. Often when he finally said something, he spoke so softly that he was inaudible and it was hard to understand what he was saying. After searching through all the video and transcripts for his class, as well as his artifacts we could only find one instance of a question/prediction for this student. This was an entry recoded in Dr's science notebook on September 22 as part of Activity 5, after the caterpillars in Dr's class had pupated. The entry, recorded for Dr by the teacher was, "when will the caterpillar turn into a butterfly?" Dr received a score of 2 (*proficient*) on P2 (collecting and recording evidence) because his science notebook contained two independent records of observations made by Dr on separate days (see Figure 1). Dr was rated *somewhat proficient* (1) on P7 because the only evidence we had for his understanding of the monarch life cycle was the drawing in his science notebook, which only shows the butterfly emerging from the chrysalis (see Figure 2, "October 6").

The child Tr was rated *proficient* (2) on most dimensions (P1-P6) and *highly proficient* (3) on P7. Although she typically required some scaffolding from the teacher, she was able to generate meaningful and relevant responses during the course of the investigation. For example, there are two clear instances of her ability to generate questions with some prompting from the teacher. The first example is an entry in her science notebook on September 8 which reads, "How do butterflies, eat, sleep and drink?" The second example comes from Excerpt 6 (see above) where Tr (referring to the caterpillars in the breeding cage) asks, "How do they get out?"

The observation records in Tr's science notebook (see Figure 2, "September 15" and "September 29") provide evidence for her *proficient* rating on P2. Tr was also rated *proficient* on P3 because she drew conclusions from her data. For example, when the classroom assistant asked Tr what she had learned from her observations Tr mentioned that the caterpillar "was really big before the chrysalis" (see Figure 2). This was indeed the case, because the monarch caterpillar reached a length of about 2 inches before it started to form a chrysalis. In contrast, the chrysalis was smaller (less than 1 inch long and a quarter of an inch in diameter). What is interesting is that this was a spontaneous comparison made by child Tr and none of the other children in the class mentioned it. She also concluded that the caterpillar was inside the chrysalis (see Figure 3). This was an inference as the child could not see into the opaque chrysalis she had been observing.

Tr was rated *proficient* (2) in her ability to communicate about her investigations. During Activity 6, Tr collaborated with the members of her small group to create a poster of the monarch life cycle (see Figure 3). Tr contributed the butterfly that follows the chrysalis. During the poster presentations which followed, Tr contributed to the discussion about the sequence of development of the monarch butterfly (see Excerpt 9).

Excerpt 9: Activity 6—Classroom 3 (October 6)

Teacher 3:	What did you see on it (the milkweed plant)?
Mo:	The caterpillar.
CA3:	The caterpillar. And what stage did we see last week?
Tr:	The chrysalis.
CA3:	So what happened to the butterfly?
C:	He is into it (referring to the chrysalis)!
Tr:	He is going to turn into a butterfly.

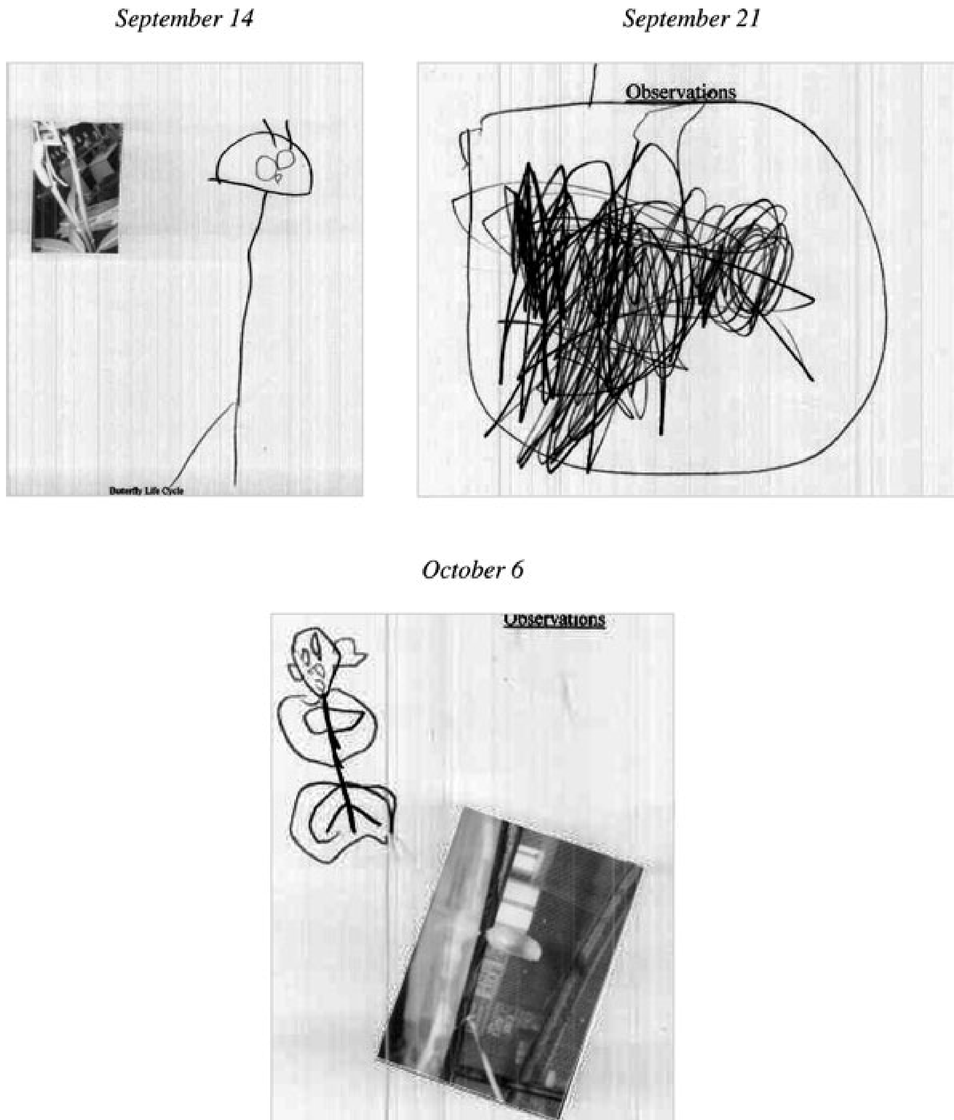


Figure 1. Excerpts from Dr's science notebook entries.

Tr was rated *proficient* on P5 because she displayed an understanding of monarch anatomy. For example, when the children were discussing insect characteristics, she spontaneously recalled that the monarch caterpillar has false legs. She also drew a butterfly with four wings on the poster of the life cycle (see Figure 3) and she counted the wings for the class during the discussion of the posters (see Excerpt 10).

Excerpt 10: Activity 6—Classroom 3 (October 6)

CA3: Tr is going to tell us about her poster. Ready Tr? What is that . . . (points to poster)?
Tr: Butterfly.
CA3: How many wings does your butterfly have?
Tr: (Counting on wings her drawing of the butterfly) One, two, three, four.

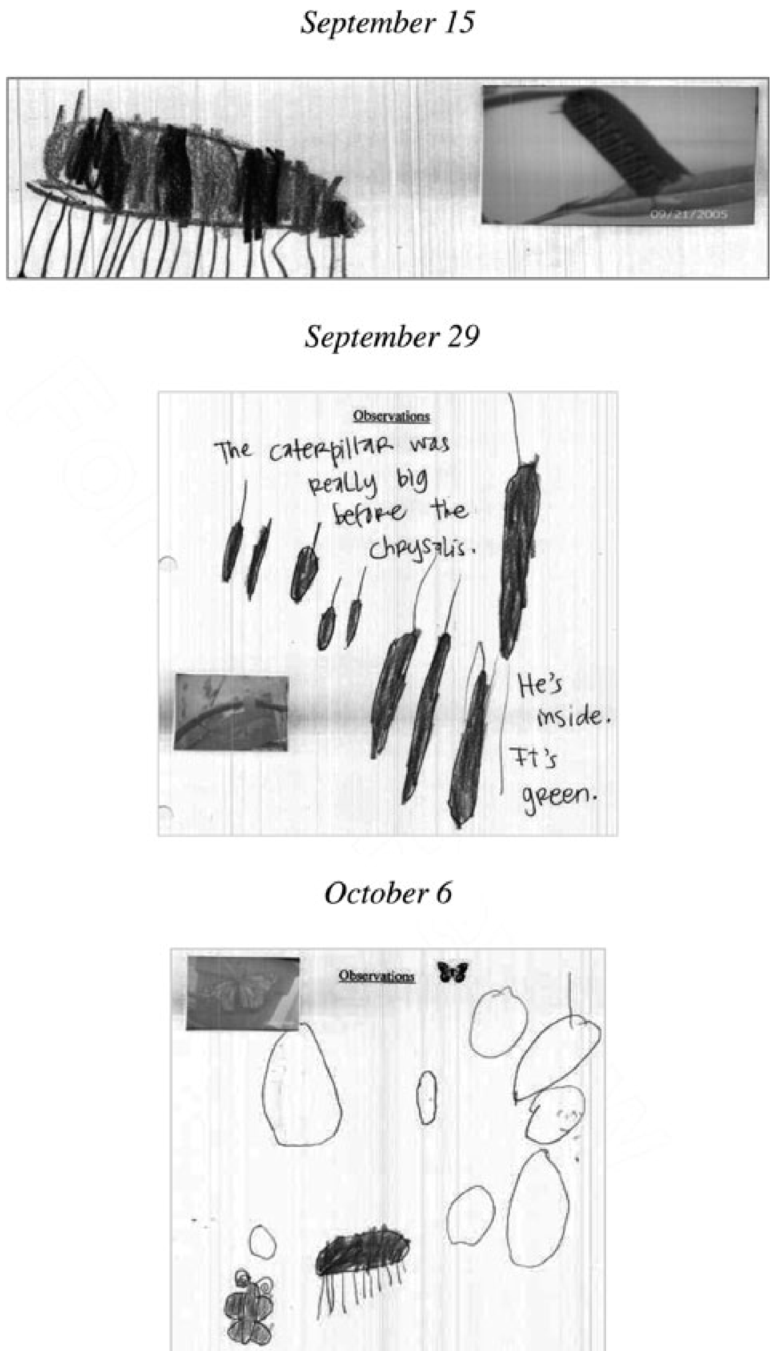


Figure 2. Excerpts from Tr's science notebook entries.

Tr was rated *proficient* on P6 because she demonstrated an understanding of adaptation in the course of small group discourse. For instance, when her group discussed what they learned about the monarch butterfly from their investigations (see Excerpt 6) Tr elaborated on child C's statement, "They're eating the leaves" by adding, "Milkweed plants." She also

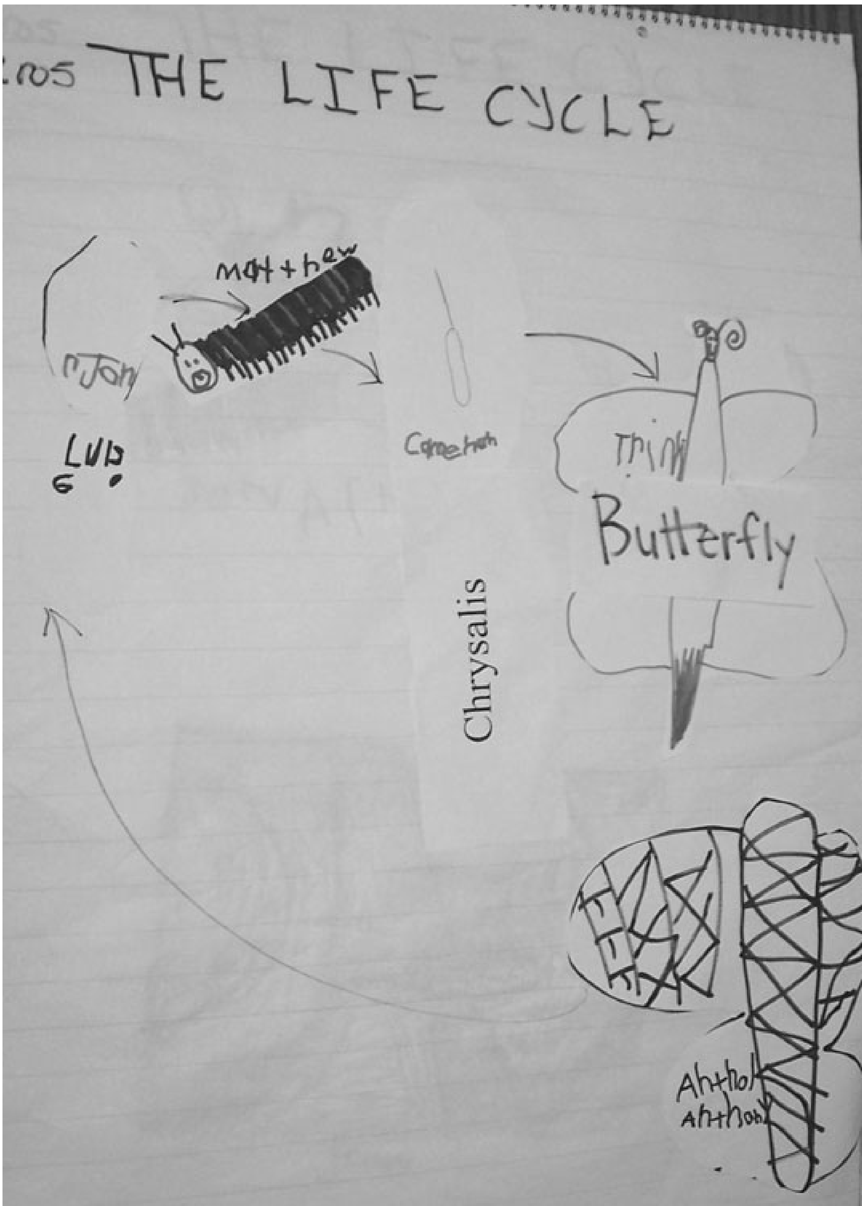


Figure 3. Poster of monarch life cycle made by Tr's group.

displayed an understanding of the difference between the artificial classroom environment of the breeding cage and the monarch's natural environment as evidenced in her question, "How do they get out?"

Tr was rated *highly proficient* on P7 because there were multiple instances where she displayed an understanding of monarch growth and development. In addition to the examples provided above, Tr also drew a model of the monarch's growth representing the key stages of metamorphosis in her science notebook (see Figure 2, "October 6"). The model depicted a butterfly, an egg, a caterpillar, a chrysalis, and another butterfly.

Composite Portfolio Scores. A composite portfolio score for each child was obtained by adding the individual scores across the seven items in the portfolio rubric. The maximum composite portfolio score possible was 21, and the minimum possible score was 0. To establish the reliability of the portfolio rating system, we asked one of the three INQ teachers (Teacher 3) to use our rating system to rate the 32 children in her two kindergarten classes. We used the composite scores derived from teacher's coding and those derived from researcher coding for these 32 children to compute interrater reliability. The interrater reliability was high ($r = .91$; $p < .01$).

Science Learning Assessment

The SLA was developed in the context of the SLP to provide a measure of science learning for kindergarten students. Key features of the instrument will be described briefly below (Samarapungavan, Patrick, et al., 2006; Samarapungavan et al., 2007). The SLA consisted of 24 items: Nine items assessed children's understanding of scientific inquiry processes and 15 items assessed their understanding of life science concepts (see Appendix for list of questions). Most SLA items followed a format in which the child was shown three pictures (each on a separate card) and asked a question about these pictures that could be answered verbally or by pointing to the correct pictures. An example is provided in Figure 4, which shows the pictures used for SLA item 2. The order in which the response

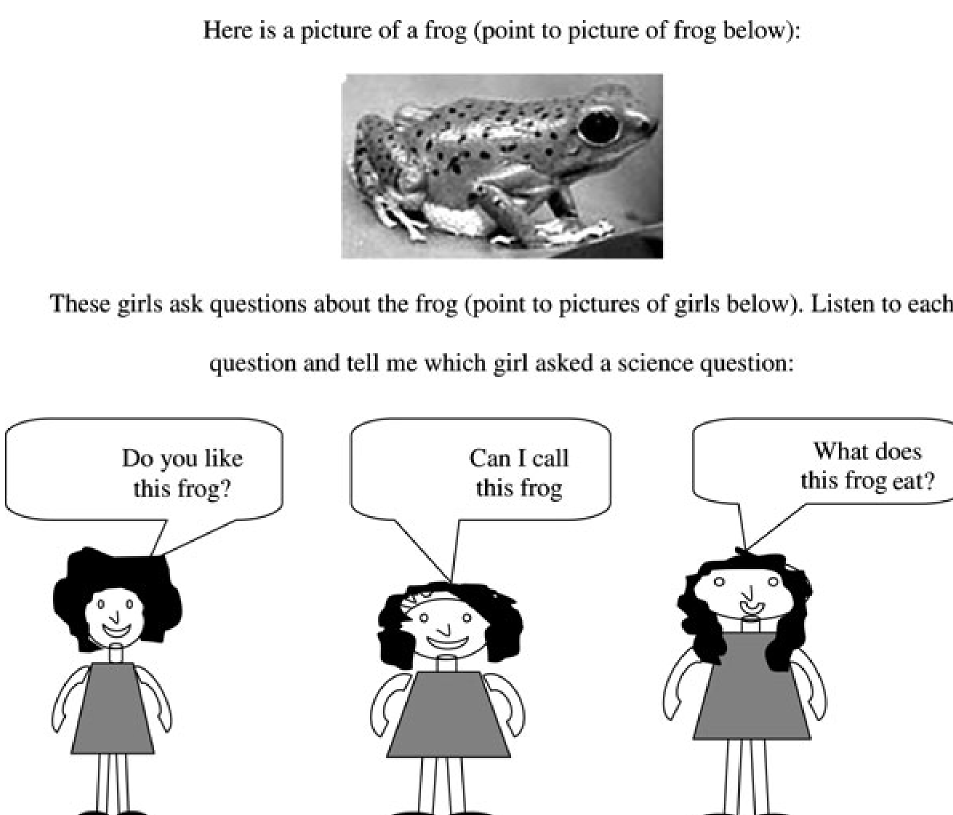


Figure 4. Schematic representation of SLA Item 2 with gray-scale versions of actual color pictures.

choice cards are presented was randomized for each child. In addition to the forced choice format described above, the SLA also included some open-ended follow-up questions. An example is SLA item 6 (see Appendix). A binary coding scheme was used to score SLA responses. Correct responses were assigned a score of 1, while incorrect responses and nonresponses were assigned a score of zero. Thus the highest total score obtainable on the SLA was 24, and the lowest possible score was 0. Reliability analyses indicate that the SLA has adequate internal consistency (Samarapungavan, Patrick, et al., 2006; Samarapungavan et al., 2007). The full-scale alpha for all 24 items in the SLA was .79.

Data Analysis

Primary data analysis was guided by the two research questions described earlier. To understand what INQ children learned from the inquiry activities, descriptive data from portfolio ratings are provided. Data are also provided about the relationship between measures of learning provided by portfolio ratings and those provided by the SLA.

Secondary data analysis compared the science learning of children in the INQ group with those in the COMP who received regular kindergarten instruction. Analyses of variance were performed to compare the total SLA scores for the two groups. In addition, chi square analyses were used to analyze the performance of INQ and COMP children by item. In the following section, we present our key findings and discuss their implications and significance.

RESULTS

Descriptive Data on INQ Children's Science Learning

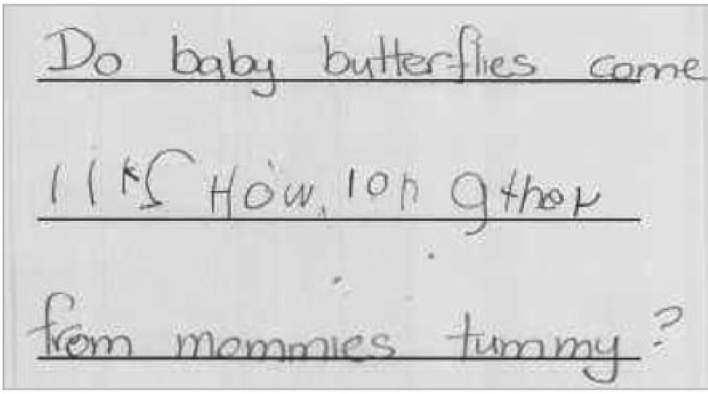
Portfolio Evidence. An analysis of variance was performed on composite portfolio scores by teacher to determine whether there were differences in performance of the children across classrooms. As no statistically significant differences were found, we will use the pooled results. Table 3 provides the frequency and percentage of portfolio ratings by item for the INQ children. Overall, a majority of INQ children were rated *proficient* (2) or *highly proficient* (3) on each dimension of science learning.

Ninety-five percent of the INQ children were rated *proficient* or *highly proficient* on P1, an indicator of their ability to ask meaningful biological questions. The children's questions reflected their awareness of important characteristics of living things such as their need for food, patterns of growth and development, and adaptations to habitat (see Figure 5 for an example).

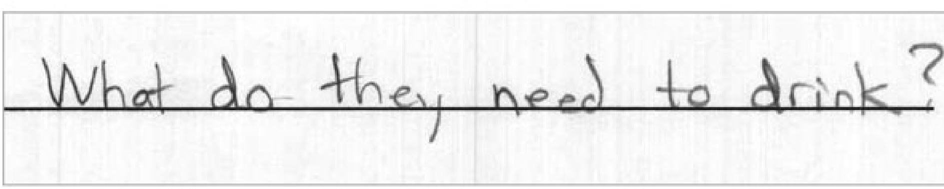
P2 was a measure of children's ability record observations relevant to their investigations of the butterfly life cycle. Ninety-four percent of children were rated *proficient* or *highly proficient* on P2 (see Table 3). Examples of the observations recorded by children in the course of their investigations of the butterfly life cycle are provided in Figures 1, 2, and 6. One of the interesting features of children's representations is that they often spontaneously combined photographs with drawings as they created models of the development of monarch larvae from their observations (see Figure 6).

P3 was a measure of children's use of empirical evidence to elaborate, extend, or revise their knowledge. Sixty-six percent of the INQ children were rated *proficient* or *highly proficient* on P3 (see Table 3). The lower ratings on this dimension stem in part from the fact that in order to be rated *proficient* on this criterion, children had to provide explicit verbal evidence that they had made inferences from their observations. We could not use children's drawings as evidence because it was not possible to clearly distinguish observations from

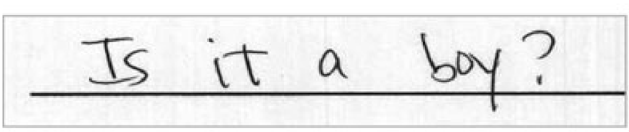
Child Li: September 6



Child R: September 5



Child Mi: September 6



Child Ma: September 6

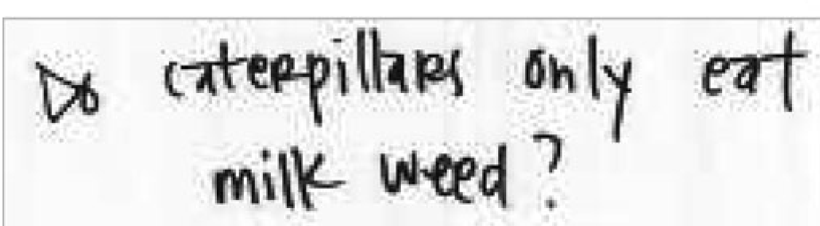


Figure 5. Examples of children's questions from their science notebook entries.

inference from the drawings alone. It is possible and indeed likely that at least some of the children who used predominantly iconic models or representations were also elaborating or revising their models of the monarch life cycle. Consider, for instance, the child Mu who started out by predicting that "Mommy butterflies" gave birth to "little baby butterflies" and insisted that the babies would look exactly like their mommies, only smaller. The last entry in his science notebook (see Figure 7) is a model of the monarch life cycle, which shows

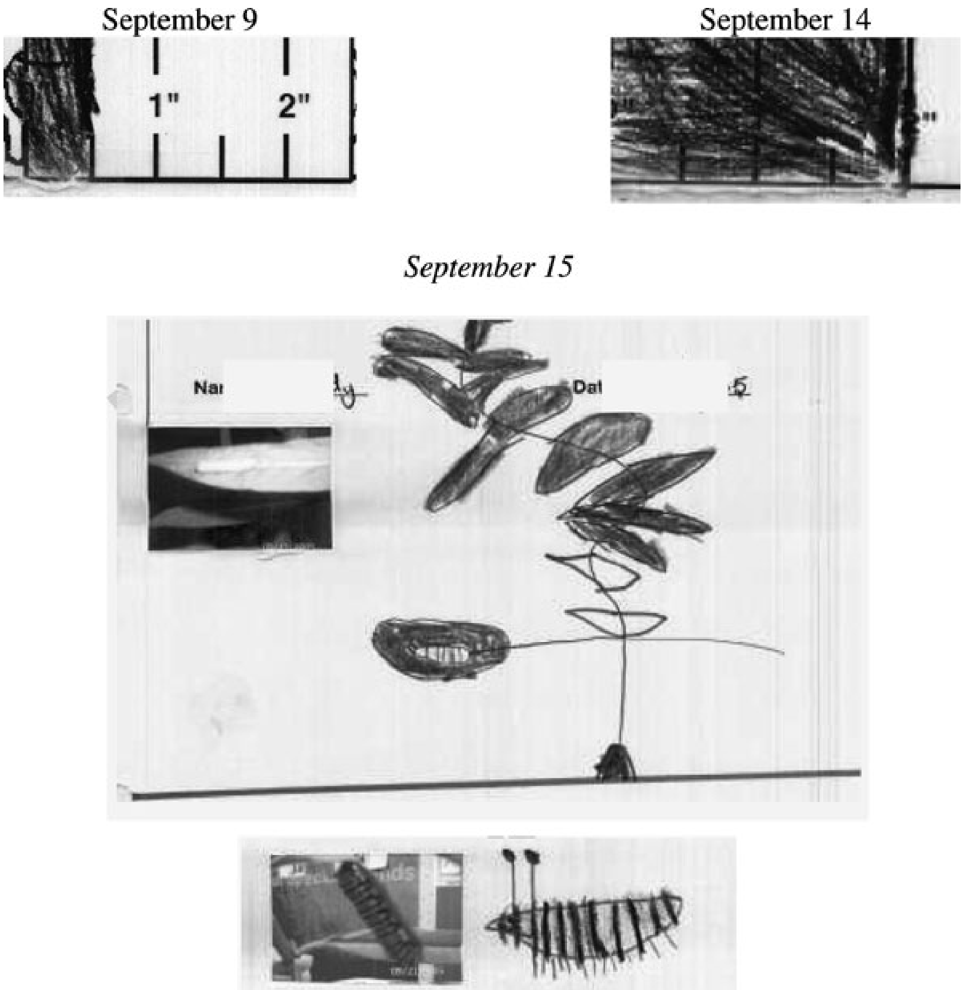


Figure 6. Examples of evidence recoded by child M.

various stages of metamorphosis (a caterpillar, a chrysalis, and a butterfly). This model is clearly different from the one Mu started out with but because he did not explicitly refer to any empirical observations as the source of his model, we do not use this model as evidence for P3.

Several children did provide explicit verbal evidence that they were making inference from the empirical evidence they had gathered to elaborate or revise their models. For example, children inferred that the chrysalis was alive because they saw it moving (a chrysalis shakes when it senses something approaching). Other children such as Kl (see Figure 8) made inferences that there was a caterpillar in the chrysalis. This is an inference because the chrysalis was opaque at the time Kl was observing it, and she could not see what was inside. Another example comes from child A toward the end of the inquiry cycle. Child A was reviewing the photographs in her science notebook and concluded that monarch butterflies come from chrysalises (see Figure 8).

P4 reflected children's ability to communicate orally about the results of their investigations in group discussion. Eighty-five percent of the INQ children were rated *proficient* or

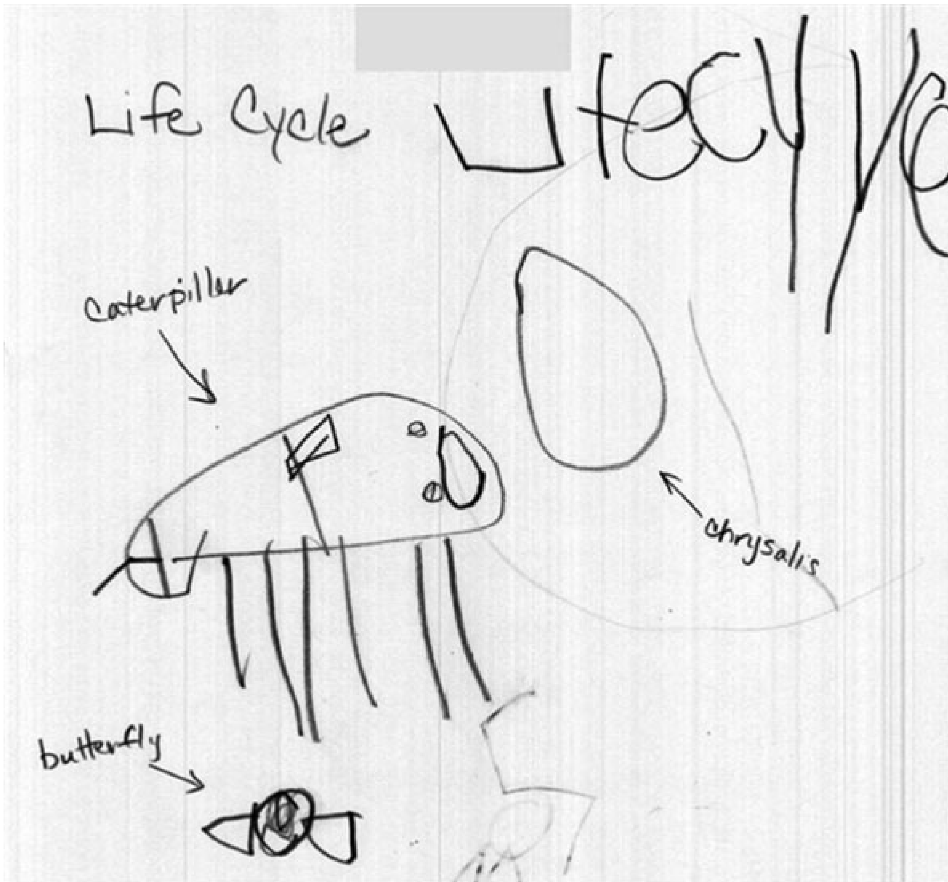


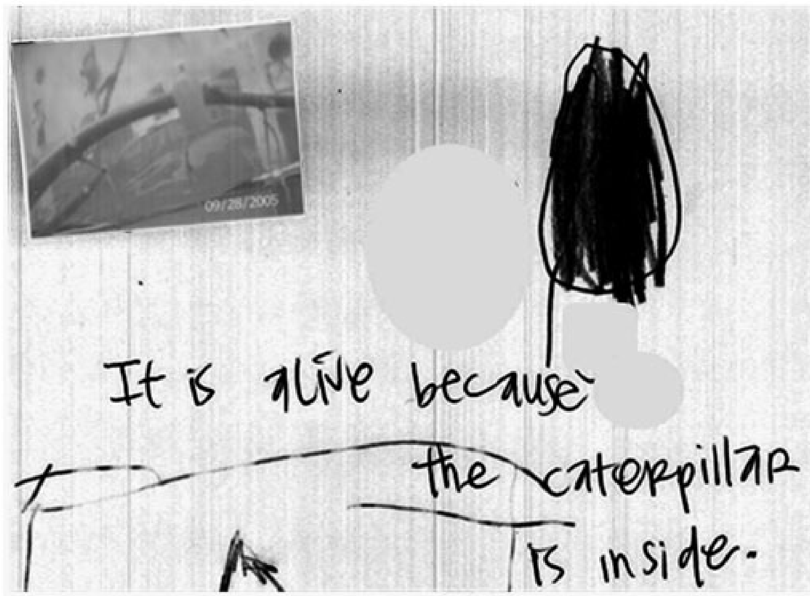
Figure 7. Model of the butterfly life cycle from Mu's science notebook.

highly proficient on P4 (see Table 3). Examples of proficiency with regard to P4 can be seen in the excerpt of classroom discourse provided earlier (see Excerpts 8-10). For examples of posters created by small groups, see Figures 4 and 10.

INQ children were able to describe key characteristics of the monarch butterfly and how the monarch butterfly was adapted to its habitat (see P5 and P6 in Table 3). Eighty-two percent of them were rated *proficient* or *highly proficient* on P5 and 72% received a rating of *proficient* or higher on P6. The children learned about several key features of monarch butterflies through various stages of their growth and development. For example, they described several structural characteristics of monarchs. For example, Li who drew the caterpillar in Figure 9 said that it "has three parts" (referring to the head, abdomen, and thorax) and "six legs." The children learned about role of the milkweed plant in the monarch life cycle and showed an understanding of camouflage as a biological adaptation (see Excerpt 6). The children also understood key stages in the growth and development of the monarch butterfly (see P7 in Table 3). Ninety-four percent of the INQ children were rated *proficient* or *highly proficient* in their knowledge of the life cycle of the monarch butterfly. Examples are provided in Figures 3, 7, and 10.

On the whole, the portfolio evidence indicates that a majority of kindergarten students in the INQ group were successful in mastering the instructional objectives of the inquiry unit (see Table 2). The portfolio data provide evidence that kindergarten children can engage in

Excerpt From Kl's Science Notebook: September 29



Excerpt from A's Science Notebook: September 29

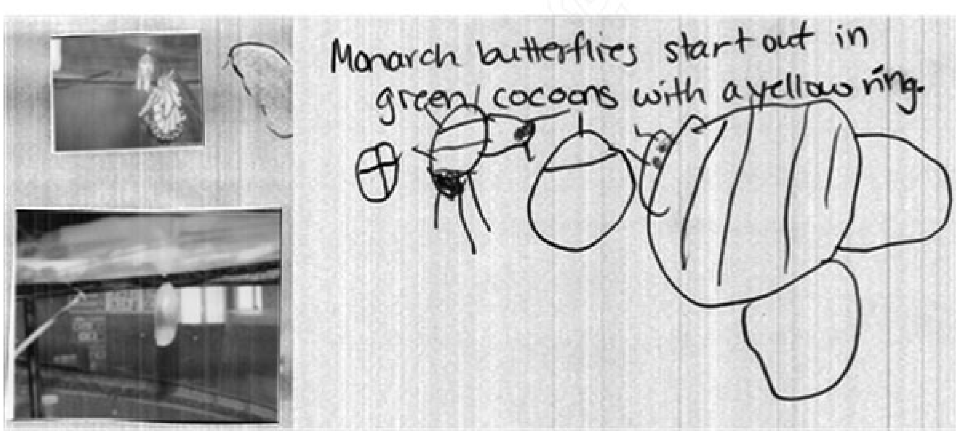


Figure 8. Examples of children's inferences from empirical evidence.

the processes of scientific inquiry and extend and revise their biological knowledge through inquiry.

SLA Results. Overall, the results of the SLA corroborate the portfolio evidence. Correlational analyses of *SLA-Total* scores with *composite portfolio* scores yielded a significant positive correlation ($r = .74$, $p < .01$).

As noted earlier, we administered the SLA to children in a second group, the COMP group, which did not receive dedicated science instruction. Because the developmental literature suggests that preschool and kindergarten children do acquire biological knowledge

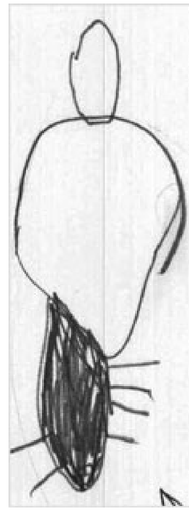


Figure 9. L's drawing of a caterpillar.

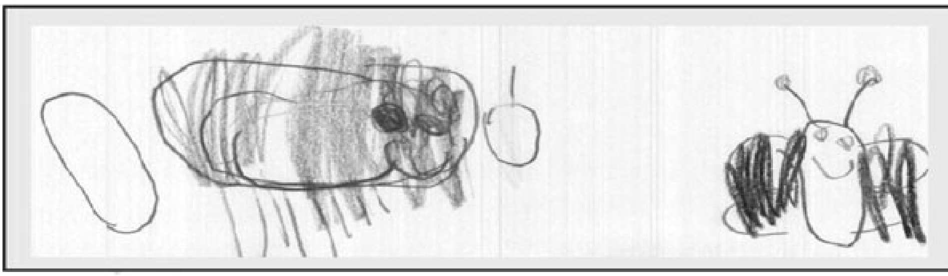
from everyday experiences even in the absence of formal instruction (Carey, 2004; Inagaki & Hatano, 2004) we thought that the COMP group might serve as a baseline against which to compare INQ group learning. ANOVA results show that INQ children scored significantly higher on the SLA than COMP children, $F(1, 98) = 44.10$, $p < .01$. The mean SLA-total score for children in the INQ group was 16.91 ($SD = 3.74$). The mean SLA-total score for the COMP group was 12.03 ($SD = 3.07$).

Table 4 shows the percentage of correct responses on each SLA item for the INQ and COMP groups (see Appendix for SLA item descriptions). χ^2 analyses were performed to determine whether the children in the INQ and COMP groups correctly answered each SLA item at a level significantly greater than that predicted by chance ($\alpha = .01$). For forced choice format items, we tested for the probability that the proportion of correct responses would equal .33 because there were three response choices. All SLA items except, 11, 13, 14, 15, 16, and 21 were in forced choice format. For constructed response items, we tested for the probability that the proportion of correct responses would equal .50, assuming an equal probability of correct and incorrect responses. The INQ children answered 20 of the 24 items correctly at levels significantly greater than chance ($p < .01$; see Table 4). In contrast, the COMP group answered only 11 of the 24 items at a level significantly greater than chance (see Table 4).

The INQ children demonstrated an understanding of key aspects of scientific inquiry such as prediction, observation, record keeping, and the use of simple tools such as magnifying glasses and science notebooks (see Q1, Q3–Q5, and Q7–Q9 in Table 4). For example in Q4, children were shown a picture of a red ball and then read three statements: (a) This ball can bounce; (b) This ball is red; and (c) My dress is green. Eighty percent of INQ children correctly identified (a) as a prediction about the ball.

INQ children performed poorly on Q2 (see Appendix) in which they were given three questions about a frog: (a) "What does this frog eat?" (b) "Do you like this frog?," and (c) "Can I call this frog Lilly?" They were then asked to identify the "science" question. Only 32% of INQ children correctly identified the science question. The SLA item that proved particularly difficult for the INQ children was Q6. Only two INQ answered Q6 about hypothesis testing correctly. Developmental research suggests that the concept of

Model of Butterfly Life Cycle from C's Science Notebook: October 6



Small Group Poster of Life Cycle by Ka, Ad, N and La: October 6

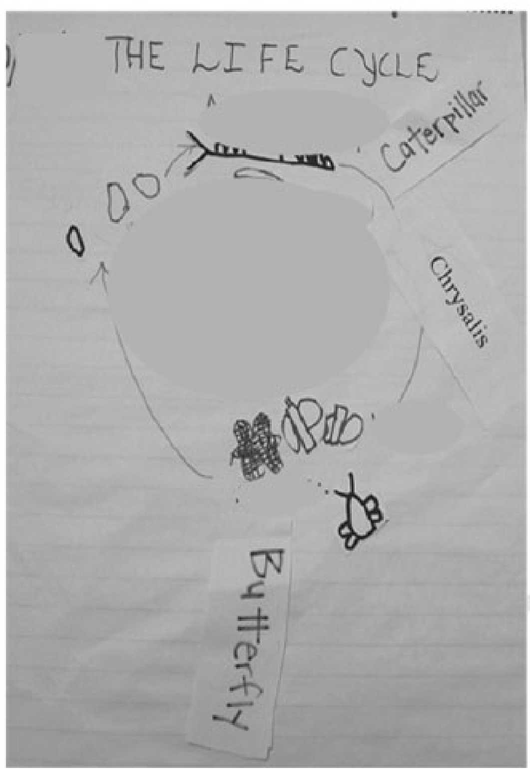


Figure 10. Examples of children's models of the butterfly life cycle.

hypothesis testing is particularly hard for young children to learn (Klahr, 2000; Kuhn, Amsel, & O'Loughlin, 1988; Kuhn & Dean, 2005; Schauble, 1996). In addition, the inquiry unit used in the current study did not explicitly focus on the concept of hypothesis testing. In Year 2 of SLP implementation, children work on six separate inquiry units, over a period of 20 weeks. Some of these units do focus on hypothesis testing and will allow us to further examine this issue.

The INQ children also demonstrated biological knowledge in their performance on the SLA (see responses on Q10 and Q11–Q24 in Table 4). They correctly answered questions about insect identification, the function of various insect body parts, the butterfly life cycle,

TABLE 4
Percentage of Correct Answers for INQ and COMP Groups by SLA Item

Item #	INQ ($n = 65$) (%)	COMP ($n = 35$) (%)
1. Doing science	74[a,b]	11
2. Science question	32	17
3. Observation—fish	83[a,b]	17
4. Prediction—ball	80[a,b]	20
5. Prediction—teeter totter	57[a,b]	29
6. Hypothesis test	3	0
7. Science tools—record	74[a,b]	29
8. Science tools—magnify	86[a,b]	69[a]
9. Science tools—measure	86[a]	97[a]
10. Choose insect (a)	92[a]	91[a]
11. Justification for 10	51[b]	11
12. Choose insect (b)	75[a,b]	51
13. Justification for 12	65[a,b]	46
14. Caterpillar structure/function—eat	74[a]	71[a]
15. Caterpillar structure/function—breathe	57[a,b]	3
16. Caterpillar structure/function—move	77[a]	94[a,b]
17. Butterfly life cycle	92[a]	80[a]
18. Camouflage—butterfly	83[a]	82[a]
19. Not camouflaged—goldfish	98[a,b]	63[a,b]
20. Choose living thing—plant	69[a]	57[a]
21. Justification for 20	60[a]	54
22. Living things need air	88[a]	80[a]
23. Living things need food	95[a]	94[a,b]
24. Identify invertebrate—crab	58[a,b]	31

COMP = comparison; INQ = inquiry; SLA = science learning assessment.
[a]The proportion of correct responses for the item is significantly greater than chance ($p < .01$).
[b]The group produced significantly more correct responses ($p < .05$).

and the distinction between living and nonliving things. For example, when shown pictures of a fern, a car, and a table, 69% of INQ children correctly identified the fern as a living thing.

One of the questions on which the INQ children performed poorly was Q11. This was a follow up to Q10 on which children were shown pictures of a squirrel, a bird, and a butterfly and asked to identify which one was an insect. Although 92% of the INQ children correctly identified the butterfly as an insect in Q10, only 51% of them could provide an identifying characteristic of insects in Q11. In contrast, 65% of INQ children (significantly greater than chance, $p < .01$) correctly provided an indentifying characteristic, typically that insects had six legs, in Q13. We believe that the better performance in Q13 can be explained by the fact that it followed Q12 on which children were shown pictures of a spider, a centipede, and an ant and asked to identify the insect. Since the three exemplars in Q12 were morphologically quite similar, we think this encouraged the children to pay attention to key differentiating characteristics such as the number of legs.

A comparison of INQ and COMP group performance by item on the SLA shows significant advantages for the INQ children. Chi-square analyses indicate that the INQ group had a significantly greater proportion of correct responses than the COMP group on 12 of the 24 SLA questions (see Table 4). Q16 was the only question on which COMP children performed significantly better than INQ children. Although 77% of INQ children answered correctly that the caterpillar used its legs to move, several INQ children said the caterpillar used its "back" to move. We think that this is a misconception they may have developed by watching the undulating motion of the monarch caterpillar (arching into an "S" shape) during their observations. The COMP children performed particularly poorly on Q1–Q7, which measured their understanding of aspects of scientific inquiry (see Table 4). Overall, the results of the SLA comparisons indicate that INQ children learned considerably more science than the baseline COMP group which did not receive dedicated science instruction.

DISCUSSION

The main objective of this study was to examine what kindergarten students could learn from inquiry-based science instruction. This was important for both theoretical and practical reasons. Theoretically, there are profound disagreements in the developmental literature about the extent to which young children possess the cognitive skills needed to engage in scientific inquiry. On the one hand, several researchers have shown that even young children are capable of simple forms of causal reasoning and can form and revise concept in ways that are sensitive to empirical evidence, when they are assessed with tasks that tap into their knowledge of the world (Brown, 1990; Metz, 1993, 2004; Brewer & Samarapungavan, 1991; Samarapungavan, 1992; Sobel, Tennebaum, & Gopnik, 2004). Other researchers have focused on children's difficulties with many aspects of scientific reasoning such as the ability to control relevant variables during investigations (Chen & Klahr, 1999; Klahr, 2000) and to coordinate concepts with empirical evidence in scientific reasoning (Kuhn, 1989, 1991). A substantial developmental literature suggests that an understanding of the nature and processes of scientific inquiry develops spontaneously, relatively late in elementary school children (Kuhn & Dean, 2004; Kuhn et al., 1988; Zimmerman, 2000). A lack of clarity about the developmental underpinnings of science learning in pre-elementary children contributes to the paucity of research on kindergarten science curricula and science learning in kindergarten.

Research rooted in sociocultural perspectives advocates more "ecologically grounded" instructional approaches that develop students' capacities for thinking about and learning science (Barab & Roth, 2006; Hammer & Elby, 2002; Lemke, 1990; Roth, 2003, 2005). For example, guided inquiry approaches are based on the assumption that scaffolding from the instructional environment (such as teacher facilitation and support through modeling and questioning, the creation of supportive task structures, the use of cultural tools to reduce cognitive load and facilitate the sharing of knowledge, and the creation of social norms for discourse) allows students to acquire rich domain knowledge and supports their capacities for thought (Brown & Campione, 1994; Magnussen & Palincsar, 1995; White & Fredericksen, 1998). Although such approaches to science instruction have been studied at the upper elementary and high school levels, there is as noted earlier little research that examines kindergarten science learning.

From a practical perspective, there is a documented lack of science instruction in early schooling in this country. National data show that only 10%–13% of instructional time is spent on teaching science in grades 1–4 (National Center for Education Statistics, 1997; Weiss, Pasley, Smith, Banilower, & Heck, 2003). What science instruction there is, typically does not engage children in the processes of scientific inquiry. For example, fewer than half of K-2 classes read science-related text or engage in inquiry-based science-learning activities, such as observing and recording or representing data, at least once a week (Fulp, 2002).

The current study provides data that have both theoretical and practical import. It extends our theoretical understanding of kindergarten children's developmental capacities for learning science in an ecologically supportive classroom context. The implementation of the SLP inquiry activities in four public school classrooms serving a linguistically and socioeconomically diverse student population provided a large and relatively robust data source for describing what kindergarten students learn from inquiry. The study also provided data on the practical feasibility as well as potential barriers to the implementation of inquiry-based science instruction for young children.

As evident from the results presented above, our findings indicate that kindergarten children are able to successfully engage in the practices of scientific inquiry and to conduct empirical investigations to extend and revise their biological knowledge. Our portfolio evidence, gathered in situ as children engaged in inquiry, indicates the richness of children's learning. Kuhn and Dean (2004, 2005) argue that part of learning to reason scientifically is the ability to generate genuine scientific questions (ones to which the answer is not known) that can be fruitfully addressed by empirical evidence. They suggest that even adults often have trouble generating genuine scientific questions, those to which they do not already "know" the answer. Both INQ and COMP children had difficulty with identifying a scientific question on the more decontextualized, "stand alone" assessment of the SLA (see Q2, Table 4). However, our portfolio evidence indicates that INQ children were able to ask genuine scientific questions and make predictions that could be addressed by empirical evidence from their investigations in the facilitative context of the classroom inquiry activities (see Figure 5). These findings are consistent with sociocultural perspectives which predict that children are more likely to realize competence in facilitative social contexts.

One of the ideas behind SLP is that engaging students in the meaningful practice of inquiry provides opportunities for both conceptual and epistemic development. Although the primary focus of this paper is on INQ children's conceptual development, there are also epistemic dimensions to the INQ children's science learning. These epistemic dimensions emerge from the contexts of practice; from children's engagement in the practices of scientific inquiry. Children's "enacted epistemologies" refer to their practical judgments and heuristics with regard to deriving, evaluating, revising, and communicating shared knowledge. The act of asking a "scientific" question or making a "scientific" prediction has epistemic as well as conceptual dimensions. A fruitful scientific question is grounded in what is already known but is designed to extend or revise knowledge (Laudan et al., 1986). In addition, scientific questions are those that are responsive to empirical evidence (Giere, 1988). In advancing questions that possessed these qualities, INQ children demonstrated an emergent, albeit applied or enacted understanding of some of the epistemic underpinnings of science. As noted earlier in the results section, INQ children asked meaningful questions not only at the beginning of their investigations, but also throughout the course of inquiry. For example, upon watching the chrysalis form, one child recorded the following question about the caterpillar: "What will he eat when he is inside?"

The portfolio evidence indicates that INQ children were able to gather and record empirical evidence, and to use this evidence to extend and revise their biological knowledge, and to communicate their investigations and their knowledge. The classroom science discourse was a key component of SLP inquiry activities facilitating both conceptual and epistemic development.

Consider for example Excerpts 1 and 2 of classroom discourse from Activity 1 provided earlier. Despite the children's clear lack of knowledge about "science" as a discipline evident in Excerpt 1, in the span of a single lesson, the teacher managed to engage them in a scientifically reasonable discussion about how to devise an investigation to determine the identity of an object (the tulip bulb). In the course of this discussion, the idea of an empirical test emerged naturally as a way past the impasses of the initial, rational arguments from prior knowledge. One of the main roles that the teacher played in the ensuing discussion was to create and sustain in the group, an epistemic need to resolve different conjectures that emerged in discussion. In this sense, we suggest that the teacher helped create epistemological resources (Hammer & Elby, 2002) for children. The ability of children to generate the idea of an empirical test in the facilitative social context of classroom inquiry activities stands in stark contrast to their poor performance on the SLA question concerning hypothesis testing (see Item 6, Table 4). We believe that longer and more sustained experiences with conducting scientific inquiry planned for future implementations of SLP may help children to transfer their contextually developing understandings of scientific inquiry to a broader range of contexts.

Classroom discourse also helped children attend to the accuracy of their observational records as they gathered data. The children often spontaneously corrected each other as they compared observations. An example can be seen in Excerpt 7 where children are taking measurements of caterpillar length. It is important to note that this activity occurred in the second month of the school year, and the children had no practical experience with measurement prior to this activity. In Excerpt 7, Cl first claimed that the caterpillar he measured was 5 inches long. Instead of correcting him, the classroom assistant merely asked him how he knew this. At this point A, who had measured the same caterpillar, interjected to correct Cl and said, "This is two, two inches (pointing to her paper). This caterpillar (pointing to the caterpillar on the plant) this caterpillar is two inches."

One of the things that the science notebook entries illustrate is young children's emerging sense of scientific representation or modeling. For example, consider the model of caterpillar growth produced by Ma (Figure 6). Ma used photographs, taken a week apart, of a monarch caterpillar they had been observing. These photographs were meant to be records of the caterpillar growth. The caterpillar grew very rapidly during the observation interval, expanding from a fraction of an inch to almost 2 inches in length. Ma also spontaneously decided to create her own drawings of the growth process. The drawings show some appreciation of scale and considerable detail in the rendering of the monarch caterpillar. We interpret representations of this sort as instantiations of children's emergent models of data. Ma rendered her caterpillar in bands of green, gold, and black, which closely resemble the monarch caterpillar's actual coloration. The "banding" of the caterpillars was a representational convention adopted by a number of children across SLP classrooms. The children were clearly striving to model what they observed as accurately as possible.

On the whole, our results indicate that INQ children did learn a significant amount of science through participation in SLP activities. The children learned about the properties of living things, the structural characteristics of monarch butterflies, their biological adaptation and habitats, and patterns of monarch growth and development. One of the most promising findings was the gain in young children's understanding of the processes of scientific inquiry.

However, teaching young children through inquiry presents unique challenges. The dual goals of engaging children's pre-existing cognitive resources in the conduct of inquiry and introducing curricular guidance to support the acquisition of new cognitive resources for learning create inevitable tensions in the design and implementation of the learning environment with regard to learner autonomy and control. The investigations themselves often generated new lines of questioning in children that the teachers were unable or unwilling to pursue because the concepts involved were too complex or not considered age appropriate. For example, the teachers were visibly uncomfortable when children asked questions about animal reproduction and tended to ignore them.

Another challenge was posed by misconceptions that sometimes arose directly from children's investigations and observations. For example, the children had learned from book readings that insects had six legs but they could clearly observe that the monarch caterpillars appeared to have more than six legs (they have eight pairs of legs). This confused both the children and the teachers who sometimes concluded that caterpillars were not insects. When the research team became aware of this problem, we were able to share information with the teachers that only the first three pairs of caterpillar legs were true legs that would be retained through metamorphosis, while the other legs were considered "false legs" and would eventually be shed with the caterpillar skin during later stages of metamorphosis. Although we were able to address this particular misconception, it is possible and indeed likely that in the course of constructing new knowledge, children develop new misconceptions that may not be detected during instruction or may be hard for teachers to address.

A particular challenge in teaching science to kindergarten students is that they are "universal" novices. In addition to a lack of experience with science as a discipline, the children are also just beginning to develop the formal cognitive tools of literacy and numeracy that are important to both schooling in general and to science learning in particular. This is a challenge in terms of teaching as well as research. For example, in order for the intervention to work as envisaged, we had to design material and social support for children's recordings of their investigations over an extended period of time. This was no easy task, and the children need a lot of scaffolding with every aspect of their activities (e.g., taking, printing, and cutting out digital photographs of evidence, writing, counting, and measuring).

Because of the vast variation in the language, literacy, and drawing skills of kindergarten children, some were clearly better able to express their ideas verbally and through drawings than others. This also created certain inequities in classroom discourse as more verbal children spoke more and more often during classroom discourse despite the best efforts of the teachers to ensure that all children had a chance to participate. As noted in the Methods section, one child (Dr) produced so little interpretable behavior or artifacts that we were unable to code him on several portfolio dimensions. We were successful in coding most children only because we had multiple contextual sources of data. For example, science notebook entries and other artifacts produced by children would have been hard to code in the absence of videotaped discourse to clarify the child's representational intent.

There are also practical logistical constraints on the implementation of sustained inquiry-based curricula in kindergarten. In our state there is as yet no funding for universal full kindergarten. Thus, the kindergarten students in the current study attended "half day" kindergarten, which is in session for two and a half hours during each school day. In addition, the schools we worked with served a large proportion of socioeconomically underprivileged students (see description of participants) and were understaffed. Consequently, the kindergarten classes were large with a typical teacher student ratio of one teacher to approximately 23 students. The teachers felt particularly pressed to teach "basic" literacy and numeracy skills because of the state-mandated standardized testing that the children would face in the first grade the following year. The administration had implemented a district-wide policy requiring the kindergarten teachers to administer a standardized emergent literacy assessment to their students three times during the academic year. This assessment, which was individually administered, also took up a fair amount of instructional time. Although funding for the SLP project allowed us to provide teachers with classroom assistants in the current study, it is unlikely that a single teacher would be able to successfully implement inquiry-based learning of the kind described here in large kindergarten classrooms in the absence of such assistance. One possible answer to such logistical problems would be for teachers to recruit parent or community volunteers to assist with inquiry activities.

One of the encouraging aspects of the project was that the teachers saw value in inquiry-based learning in terms of children's engagement in learning. One teacher reported that during the period of the intervention, the first thing that her students would do each morning as they came to class was to run over to the breeding cage to check on the monarchs. The teachers also mentioned that they were surprised at the complexity of the scientific concepts and vocabulary that their children were able to learn through inquiry.

Conclusions and Directions for Future Research

Data from the current study show that kindergarten children are able to acquire rich biological knowledge as they engage in the processes of scientific inquiry. While the results of the current study are encouraging, further research is needed to fully understand the scope and robustness of young children's science learning from the kinds of guided inquiry experiences provided in the context of SLP. Research is currently underway to more fully examine the epistemic dimensions of learning in SLP in terms of teacher–student and student–student interactions during classroom discourse.

We greatly appreciate the involvement of the teachers and children in this study.

APPENDIX

Item Descriptions: SLA

[The correct answers to each question are italicized and appear first. During actual administration of the SLA the response options are presented in random order.]

1. Here are picture of three children (show pictures): (a) *Gina observes a butterfly*; (b) Tom plays the guitar; (c) James practices dancing. Which of these children is doing science?
2. Here is a picture of a frog (show picture). These girls ask questions about the frog (show pictures). Listen to each question and tell me which girl asked a science question: (a) *What does this frog eat*? (b) Do you like this frog? (c) Can I call this frog Lilly?
3. Here is a picture of a fish (show picture of black and white striped fish). Here are three boys (show pictures). I will tell you what each boy said about a fish. (a) *That fish has black and white stripes*; (b) I have a pet goldfish at home; (c) Fish like to swim in groups. Which of these boys saw the fish in this picture?
4. Here is a picture of a ball (show picture of red ball at rest). Here are three girls (show pictures). I will tell you what each girl said: (a) *This ball can bounce*; (b) This ball is red; (c) My dress is green. Which of these girls made a prediction about the ball?
5. Tony, John, and Gina are on the playground (show picture: John and Gina are on the teeter totter. John is on the end that is down to the ground and Gina is on the side that is up in the air. Tony is standing beside them). Listen to what each child says. Then tell me which child makes a prediction about the teeter totter: (a) *Tony says, "If I push down on Gina's side, John will go up."* (b) John says, "I want to go up Gina." (c) Gina says, "I am having lots of fun." Which of these children makes a prediction about the teeter totter?
6. (Show pictures) Two girls found an egg. The girl in green thinks it is a duck egg. The girl in blue thinks it is a goose egg. How can they find out what it is? (Correct answer: watch it hatch/study its shape, color, etc.; partially correct answer: ask expert)
7. Here are some tools we use to do science (show pictures): Which of these can you use to help you remember what you saw? (a) *Science notebook*; (b) Magnifying glass; (c) Stopwatch.

8. Here are some tools we use to do science (show pictures): Which of these can you use to look at something very small such as a bug? (a) *Microscope*; (b) Rain gauge; (c) Digital scale.
9. Here are some tools we use to do science (show pictures): Which of these can you use to measure how hot something is: (a) *Thermometer*; (b) Rain gauge; (c) Pan scales.
10. One of these animals is an insect (show pictures): Which one? (a) *Butterfly*; (b) Bird; (c) Squirrel.
11. (Follow-up to 10). How do you know that this is an insect? (Correct answer: six legs)
12. One of these animals is an insect (show pictures): Which one? (a) *Ant*; (b) Centipede; (c) Spider.
13. (Follow-up to 12). How do you know that this is an insect? (Correct answer: six legs)
14. This is a picture of a caterpillar (show picture). What parts of the body does the caterpillar use to eat? (Correct answer: says "mouth" or points to mouth on picture).
15. (Use picture for 14). What parts of the body does the caterpillar use to breathe? (Correct answer: says "holes on side," etc., and/or points to spiracles)
16. What parts of the body does the caterpillar use to move? (Correct answer: says "legs," and/or points to legs)
17. These pictures show how a butterfly is born and grows and changes through its life (show pictures in following order: egg; monarch caterpillar; empty slot; monarch butterfly). Look at the three pictures below. Look at the three pictures below (show pictures): (a) *Monarch chrysalis*; (b) House fly; (c) Miniature version of monarch butterfly. Which of these is should go up here (point to missing picture) to complete the butterfly life cycle?
18. Here are some pictures of plants (show pictures of two plants, one with green foliage and one with orange and brown foliage). On which plant should this butterfly stay (show picture of monarch butterfly) so that it won't be seen? (Correct answer: *plant with orange and brown foliage*)
19. Here are some pictures of animals (show pictures). Which of these is NOT camouflaged? (a) *Orange goldfish in green pond water*; (b) Brown/grey toad on brown/grey tree trunk; c) Grey moth on grey tree bark.
20. Which of these is a living thing (show pictures)? (a) *Plant*; (b) Car; (c) Table.
21. (Follow up to 20). Why is it a living thing? How can we tell that it is a living thing? (Correct answer: names two or more characteristics of living things—e.g., grows, needs food or water, breathes, moves on its own, etc.)
22. (Show pictures) One of these needs air to breathe: Which one? (a) *Dog*; (b) Doll; (c) Balloon.
23. (Show pictures) One of these needs food: Which one? (a) *Ant*; (b) Robot; (c) Bicycle.
24. (Show pictures) One of these has no backbone: Which one? (a) *Crab;* (b) Damselfish; (c) Girl.

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